

A consideration of various factors affecting the net duty of irrigation water

Prof. Charles Derleth, By at Magineering.

Philip Rowland Roosegaarde Bisschop B. S. (University of South Africa) 1918

of the College of ClarksTagineering, I herewith

In accordance willing the

Submitted in partial satisfaction of the requirements for the degree of

MASTER OF SCIENCE

in April 19

Civil Engineering

in the

GRADUATE DIVISION

of the

UNIVERSITY OF CALIFORNIA

S. T. Handing Instructor in Charge Approved

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#### By

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Instructor in Charge

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### Letter of Transmittal

Prof. Charles Derleth, Jr., Dean of the College of Civil Engineering, University of California.

Dear Sir: ne moisture contained in the soil

In accordance with the regulations of the College of Civil Engineering, I herewith beg to submit to you for your approval my Thesis for the degree of Master of Science.

I remain, Sir,

Yours faithfully,

Furrow irrigation .....

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ilip/()issch Character of Soil and Bubsoi

Berkeley, April 30th, 1921.

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TABLE OF CONTENTS	Page
Letter of Transmittal	
<u>Chapter I</u> Introduction Definition of net duty and max- imum economical duty	141
<u>Chapter II</u> <u>The Texture and Structure of the Soil</u> Grades of soil Structure of the soil The moisture contained in the soil	
<u>Chapter III</u> <u>The Climate</u> The annual precipitation and its distribution The start of the Irrigation System	28 
<u>Chapter IV</u> <u>Moisture Distribution in the Soil</u> Downward, upward and lateral movement of soil moisture The extent of distribution Results of field experiments Conclusions reached	
	325
<u>Chapter V</u> <u>Character of Soil and Subsoil</u> Hardpans Gravel and sandy subsoils	
<u>Chapter VI</u> <u>Evaporation, Percolation and Surface Waster</u> <u>Losses</u> The process of evaporation. Cultivated and uncultivated soils. Mulching. Furrow irrigation. The effect of the type of soil on per- colation losses. Size of irrigation head. Frequency of application.	· · · · · · · · · · · · · · · · · · ·
Length of run Lateral percolation in furrows Surface waste	

Page	TABLE OF CONTENTS
	Letter of Transmittal
1	Chapter 1 Introduction Definition of net duty and max- imum economical duty
14  	Chapter 11 The Texture and Structure of the Soil Grades of soil Structure of the soil The moisture contained in the soil
28 	Chapter III The Climate. The annual precipitation and its distribution The start of the Irrigation System
	Chapter IV <u>Moisture Distribution in the Soil</u> Downward, upward and lateral movement of *soil molsture The extent of distribution Results of field experiments
61  	Chapter V Character of Soil and Subsoil Hardpans Gravel and sandy subsoils
67	Chapter VI <u>Eveporation. Percolation and Surface Waste</u> <u>Losses</u> The process of eveptration Cultivated and uncultivated soils
•••	Mulching Furrow irrigation The effect of the type of soil on per- colation losses Size of irrigation head
	Frequency of application Length of run Lateral percolation in furrows Surface waste

Chapter (VII erences are indicated by number.) The Fertility of the Soil	93
Need of fertilizers	
Solls-1, The function of organic matter in the soil	
PrinciplesCoverscrops	
Chapter VIII DeinageKing.	99
The Crops	
The effect of irrigation at different	
invigation inperiods of plant growth	
American irrigation practice on dif-	
Diversification of crops	
Chapter IX	109
Yields of Various Crops under Varying	
Amounts of Irrigation Applications	
Results of experiments on (1) Alfalfa	
(2) Potatoes	
Distribution (3) Cereals	
(4) Citrus fruits	
(5) Deciduous fruits	
Chapter X	128
Tables (1) The net and gross duty of various	
(1) The net and gross duty of various	
irrigation projects for the year 1917	
(2) Distribution of irrigation water for	p
net duty on various projects for	- Treas
122 Note the years 1912-1919	
(3) Average seasonal duty of water on	
various Irrigation Projects for the years 1912-1917	
The sovement of Weter in Irrigated Soile-Widtace	

College Experiment Statelon, Bulletin 117.

Page

1.1

Page	
Chapter VII The Fertility of the Soil. Need of fertilizers. The function of organic matter in the soil	
<pre>99 Chapter VIII The Groos Plant growth The effect of irrigation at different periods of plant growth American irrigation practice on dif- ferent crops</pre>	
Chapter IX <u>Vields of Various Crops under Varying</u> <u>Amounts of Irrigition Applications</u> (1) Alfalfa (2) Potatoes. (3) Cereals. (4) Oltrus fruits. (5) Deciduous fruits.	
Chapter X Tables (1) The net and gross duty of various irrigation projects for the year 1917 (2) Distribution of irrigation water for net duty on various projects for (3) Average seasonal duty of water on yarious Irrigation Projects for	

the years 1912-191

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- 20. Water Requirements of Soils in the Sunnyside Valley Irrigation District--Harding.
- 21 Report on Irrigation Investigations at Billings, Montana--Harding.
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- 23. The Use of Water from the Tuolumne by the Modesto and Turlock Irrigation Districts--Etcheverry and Means.
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### CHAPTER I

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### INTRODUCTION

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It is well recognized that, regardless of the crop irrigated, a proper knowledge of the duty of water is essential to both the Farmer and the Engineer. Such, especially, is the case in newly developing irrigated and irrigable districts. With the growth and development of the irrigated sections the question of advantageously and economically using the limited amount of irrigation water is becoming more and more apparent. As the irrigable lands become more settled, more frequently is it asked just how much water is necessary to produce a good crop, and under what conditions of irrigation can the largest returns per acre foot of water as well as per acre be expected.

In South Africa especially, in its present period of development, is it essential that more definite information on which to base an answer to these questions, be obtained. It is a matter of extreme regret that up to the present no experiments, to determine the water Duty of our South African crops under the many varying climatic conditions, have as yet been undertaken.

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have this information that he may make the arrangement for an adequate water supply, that he may avoid injury of his soil through the application of too much water, and that he may adjust to his land the amount available to him, so as to obtain the largest possible returns per acre foot of water applied. Further, he should have an of understanding/the underground movement of the water after its application, that he may be sure, on the one hand, that excessive losses are not occurring through deep percolation, and, on the other hand, that the irrigation water is penetrating into the soil sufficiently deep to give proper nourishment to the feeding roots of his crop.

It is essential to the Engineer to have such information at his disposal in order that he may determine how large a canal to build to supply a definite area, or, having determined the quantity of water available and the cost of bringing it to the tract to be irrigated, he could not decide upon the practicability of his scheme because of his inability to determine how large an area the water supply is able to serve.

The Engineer, too, should have an accurate knowledge of the factors that influence the amount of water have this information that he may make the arrangement for an adequate water supply, that he may avoid injury of his soil through the application of too much water, and that he may adjust to his land the amount available to him, so as to obtain the largest possible returns per acre foot of water applied. Further, he should have an understanding the underground movement of the water after its application, that he may be sure, on the one hand, that excessive losses are not occurring through deep perter is penetrating into the soil sufficiently deep to give proper nourishment to the feeding roots of his erop.

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The Engineer, too, should have an accurate knowledge of the factors that influence the amount of water used to mature a crop after its application to the soil. Such matters as the spacing of the furrows in orchard irrigation, the length of run and the corresponding most economical head of water to be used, frequency of application are of vital interest to the success of an irrigation scheme.

Again, we shall not be able to place on our statute books more logical laws concerning the proper use of water, or to enable our judges to render more satisfactory decisions in water disputes, until we have gathered a large amount of data, under properly controlled conditions, relative to the behaviour of water when brought upon soils for the production of crops.

The "duty of water" is a phrase which expresses the relationship existing between a given quantity of water and the area of land that it is made to serve. This amount may vary between the wasteful application of water on prepared lands in an unscientific way to the highly refined experimental methods as used for instance in Southern California, Where according to F. R. Adams "the water carried has the exceptional agricultural value of one thousand dollars per miner's inch."

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It is therefore, in order to be more definite, perhaps advisable to use the phrase "the reasonable water requirements," which may be defined as "the use of that quantity of water which represents good practice when the character of the soil, topography of the land, value of the water, crop and other economic conditions are taken into consideration." It is in general that quantity of water with which the average farmer should obtain the best results without undue waste.

It is, of course, obvious that this quantity cannot possibly be permanently fixed and must necessarily vary not only with the physical and topographical conditions under which the water is applied, but also upon the economic conditions affecting the value of the water and the resultant crop.

It may be expressed as the number of acres that may be irrigated by a definite quantity of water, usually a second foot or cusec, flowing continuously throughout the irrigation season. The most commonly used unit is, however, the acre foot, which represents a volume of water equivalent to a depth of one foot on an area of one acre.

The Gross Duty for an entire System is made up

It is therefore, in order to be more definite, perhaps advisable to use the phrase "the reasonable water requirements," which may be defined as "the use of that quantity of water which represents good practice when the character of the soil, topography of the land, value of the water, crop and other economic conditions are taken into consideration." It is in general that quantity of results without undue waste.

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Pectors

The net Duty represents the actual amount of water delivered to the land and includes such losses as that by evaporation, percolation and waste, in addition to the actual amount that is absorbed by the plant. 5

The Gross Duty is the relation between the total irrigated area under the System and the amount of water diverted from the source of supply. The factors that influence the gross or entire duty of a Scheme are as many and as varied as the conditions under which an irrigation scheme operates. An attempt to summarize all thesëis shown in the following table:

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correspondently addresses appropriation and granting

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of the net Duty and the Loss in transmission.

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{		(Quantity 6 (Distribution
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FACTORS (Factors	(sion	( (3.Kinds of (Lined & Unlined ( ditch (Cross Section
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that this point	tion	(Dry mulch (Ordinary cultivation (Cover crop
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	Crops	(Length of growing season (Diversified or not
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(rected (	Methods of payment	Based on quantity rate (Based on flat rate

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( stream to the land		)	
(9 Soft Harmonit (200)	Losses in	)	
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	1	(	
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Cover crop	1	2	
		1	
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All these factors do much to increase or decrease the area that may be served by a given quantity of water. There remains, as a disturbing factor, the law that the more water that is added to a crop, the smaller will become the wield per unit of water served. This law of increasing water cost raises the question of whether the water should be used to obtain the largest possible yield per acre or whether moderate quantities shall be used to obtain the largest yield per acre foot of water 0.07%5 Sore served.

7

There is a depth of water for each type of land, crop and water conditions, which will provide a maximum profit. When water is added to a greater or less extent the amount of profit will vary accordingly. It is only with an increase of our knowledge of the duty of water that this point of "optimum" water, or of maximum benefici-From the shove, it will al use, can be determined for different crops and climatic was obtained when the 30 acre inches were spread conditions.

spread over more or less land this The following example will illustrate this point largest profit per acre was obtained more clearly. (2)

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over three asyss.

A beet field is supplying beets to the factory at a contract price of five dollars per ton. The total cost of producing the crops, including interest on the inAll these factors do much to increase or decrease the area that may be served by a given quantity of water. There remains, as a disturbing factor, the law that the more water that is added to a crop, the smaller will become the yield per unit of water served. This law of increasing water cost raises the question of whether the water should be used to obtain the largest possible yield per scre or whether moderate quantities shall be used to obtain the largest yield per acter foot of water served.

7

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The following example will illustrate this point more clearly.

A beet field is supplying beets to the factory at a contract price of five dollars per ton. The total cost of producing the crops, including interest on the investment, may be assumed to be thirty dollars per acre. Tabler I may be then constructed on the basis of the crop yield in the Utah experiments (see Bulletin 115, 116 and 117 Experiment Station) on the effect of varying quantities of water on the growth of crops.

sconomical duty will be decided on whether the surplus pro-

1	of wa-	of beets per acre	yield of beets (tons)	'paid 'for 'ton 'of	'in- 'come 'from 'beets	per acre	tal cost	in- come	llet in- come from acre
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2 acres	1 15"	19.5	1 1 39 1	1   5 	195	60	120	75	37.50
3 acres	10"	18.6	1.56	5	280	60	180	100	33.33
4 acres	1 7.5 <sup>11</sup>	16.3	65	5	' 325	60	240	1 85	21.25

From the above, it will be seen, that the largest net aggregate income, was obtained when the 30 acre inches were spread over three acres. When spread over more or less land this amount decreased. The largest profit per acre was obtained with a thirty inch application, being seven and one-half dollars above that with the fifteen inch application. In the table the cost of the water has not been taken into account, vestment, may be assumed to be thirty dollars per sore. Tabler I may be then constructed on the basis of the crop yield in the Utah experiments (see Bulletin 115, 116 and 117 Exporiment Station) on the effect of varying quantities of water on the growth of crops.

8 1

Net 1n- come from acre	in- come from	tal cost	per acre	in- come from beets	for for ton of	yield of beets (tons)	of beets per	of wa- ter on each scre	50 acre inches applied over
\$45	\$45	00 \$	034	\$1.05	\$5	21	21.0	50 <sup>11</sup>	l sere
37.50	75	120	08	195	5	39	19.6	15"	2 acres
53.53	100	180	00	088	5	.56	18.6	10"	3 seres
21.25	85	240 '	00	325	5	65	16.3	7.5"	4 20108

From the above, it will be seen, that the largest net aggregate income, was obtained when the 30 acre inches were spread over three acres. When spread over more or less land this amount decreased. The largest profit per scre was obtained with a thirty inch application, being seven and one-half dollars above that with the fifteen inch application. In the table the cost of the water has not been taken into account, and the question of what is the maximum economical yield will therefore be dependent on whether the surplus profit of seven and one-half dollars will compensate for the cost of the extra fifteen inches of water applied. Similarly in the fifteen and ten inches application, the maximum economical duty will be decided on whether the surplus profit of four dollars and thirteen cents will compensate for the cost of the extra five inches of water applied.

The differences between the net duty, the water requirement for maximum per acre yield and the water requirement for maximum economical per acre yield, should therefore be clearly kept in mind.

"The conect water requirement for maximum per acre yield is that quantity of water which is necessary to produce a maximum yield per acre, when the losses of water by percolation, evaporation and waste, which can be controlled by skilful methods of irrigation and cultivation, have been eliminated.

The water requirement for maximum economical yield from a limited water supply is that quantity of water which correctly used will give the maximum total net returns from a limited water supply and is dependent on the value of the water, the value of the land, the cost of irrigating, the cost of producing the crop and the value of the crop. The net duty merely represents the volume of water which is used according to the available water supply, the judgment and the skill of the

and the question of what is the maximum economical yield will therefore be dependent on whether the surplus profit of seven and one-half dollars will compensate for the cost of the extra fifteen inches of water applied. Similarly in the fifteen and ten inches application, the maximum economical duty will be decided on whether the surplus profit of four dollars and thirteen cents will compensate for the cost of the extra five inches of water applied.

The differences between the net duty, the water requirement for maximum per acre yield and the water requirement for maximum economical per acre yield, should therefore be clearly kept in mind.

"The conect water requirement for maximum per acre yield is that quantity of water which is necessary to produce a maximum yield per acre, when the losses of water by percolation, evaporation and waste, which can be controlled by skilful methods of irrigation and cultivation, have been eliminated.

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irrigator. Where water is cheap and abundant throughout the irrigation season, the net duty will often exceed the water requirement for maximum per acre yield, because the consequent low price does not enforce careful irrigation and cultivation methods. Where water is scarce and therefore valuable, which is the usual case for a great part of the arid region, the net duty will approach the correct water requirement for maximum total economic yield. "(6)

The amount of water that will produce the largest per acre yield of a certain crop is by no means at any time the most economic Duty. It becomes therefore imperative to undertake sufficient experiments to obtain this information for all the standard crops.

Theoretically, the aim in irrigation should be to obtain the highest possible efficiency out of every inch of rainfall and every supplementary acre inch of irrigation, and to use the least amount of the latter necessary to maintain a favourable moisture content throughout the main part of the growing season, while still permitting the soil to dry out sufficiently to mature the crop. Irrigation should be applied when the soil moisture content drops to near the wilting point, and in just a sufficient amount to raise the moisture content to the maximum usable water capacity of the soil throughout the root zone. irrigator. Where water is cheap and abundant throughout the irrigation seeson, the net duty will often exceed the water requirement for maximum per acre yield, because the consequent low price does not enforce careful irrigation and cultivation methods. Where water is scarce and therefore valuable, which is the usual case for a great part of the arid region, the net duty will approach the correct water requirement for maximum total economic yield."(6)

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Proper irrigation supplies a favourable moisture condition and encourages the growth of feeding roots, bacterial activity, and the liberation of plant food. Improper irrigation checks these processes and often causes unfavourable soil temperature and drainage problems, or the leaching of plant food. Proper irrigation tends to produce optimum moisture content conditions. Again, there is always a tendency under irrigation to compact the soil and to exclude the air. It is exceedingly important, therefore, to practice rotation, including soil building crops which will offset this tendency of the soil to compact and make it practicable to maintain a high state of tilth with a high percentage of organic matter. It is the intention to discuss in this thesis these influences which may modify the net Duty of water, rather than the many, varied and complex factors, enumerated above, which go together to form the Gross Duty of an Irrigation System.

That it is well worth our time to give careful study and investigation to this particular phase of the question is borne out by the following general figures of the disposal of irrigation water after its application to the soil.

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Surface waste 5--15 percent Deep percolation losses 20--50 " Soil evaporation " <u>10--20</u> " Total " 35--85 " Amount available for

plant transpiration 65--15 "

It will be seen that even under the best of conditions, the losses will usually amount to thirty-five percent of the water applied.

> "While these losses appear high and while they can be reduced under proper methods of irrigation, the expense of their reduction may, in many localities, exceed the present value of the water saved. Where the losses are excessive, the best crops are usually not secured and it will pay to improve the method used and reduce the losses to reasonable amounts."(Harding)

Whilst it is unquestionable that the major part of this loss is due rather to the mechanical factors of the application of the water to the land--factors which even under the very best of conditions are often not practicable to modify--a greatly increased efficiency of the water should be obtained from a proper knowledge of the more theoretical considerations of the question. It is rather with this part of the problem to which this discussion will be limited. Any improvement on the practical Surface waste 5--15 percent Deep percolation losses 20--50 " Soil evaporation " 10--20 " Total " 35--85 " Amount available for

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side is an entire local question, to be solved by each individual project according to the prevailing conditions. A discussion of this side of the question could at the very best only be most indefinite. On the other hand theoretical considerations lead to definite principles which if followed expeditiously should help to secure not only a higher increased Duty on existing schemes, but also give much more definite information as to the probable irrigable area under a projected scheme.

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### CHAPTER II

THE TEXTURE AND STRUCTURE OF THE SOIL

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It is now perhaps universally recognized that the character of the soil has more influence upon the Duty of water, in the sense of the reasonable water requirement, than any other factor. It is the texture and structure of the soil which to a large extent determines the amount of water that is lost by deep percolation, carrying with it below the root zone a considerable amount of valuable plant It is also the texture and structure of the soil food. which determines the lateral movement of the water for equal distribution under furrow irrigation, as well as the upward movement with its consequent evaporation. A brief survey of some of the importance characteristics of soils will help in obtaining a clearer perspective of the various influences to which irrigation water is subjected. Arbitrarily speaking, soils may be divided into seven grades or "separates", comprising fine gravel, coarse sand, medium sand, fine sand, very fine sand, silt and clay. This grouping, established by the United States Bureau of Soils, is dependent on the size or tecture of the soil particles, varying from 2--1 mms. in diameter for fine gravel to diameters below .005 mms. for a of this pore space the passage clay.

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clay.

As these groups vary in size they exhibit properties, especially in regard to the moisture content, which vary widely, which again are imparted to the soil of which they are members.

These clay particles are very minute, jagged and angular in outline. They are highly plastic, and when rubbed together become sticky and impervious. They shrink on drying and re-expand on being melted. The finer part of the clay consists of calloids, which, because of their fineness of division, exhibit certain well defined properties, of which absorption of moisture and high plasicity and cohesion are the most important. Silt exhibits the same qualities, but to a much less marked extent. The presence of clay imparts to it a heavy texture, with a tendency to very slow water and air movement. Its water holding capacity is high. The soil is highly plastic, becomes sticky when too wet and hard and cloddy when too dry.

The sands and the gravels function more as separate particles. They are irregular and rounded, exhibit very low plasticity and cohesion and as a consequence are little influenced by changes in water content. Their water holding capacity is low, and because of the large individual size of the pore space the passage of water is rapid. In As these groups vary in size they exhibit properties, especially in regard to the moisture content, which vary widely, which again are imparted to the soil of which they are members.

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It is a well known fact that the soil particles are not homogeneous in size; neither do all the particles function as simple grains, being gathered together in groups called granules or crumb structure. A small particle of soil may be made up of a number of very small grains placed in between somewhat larger particles, resulting in a reduction of the pore space. A soil having such restricted pore space is said to be in a puddled condition. The condition is detrimental to plant growth, impeding the root development, but also preventing the circulation of air and water; a most necessary function for plant growth.

On the other hand, when a soil is made up of complexes of soil granules an increased pore space will occur. There will therefore be a very wide range of pore space ranging for the different types of soils as shown by Table II.

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Bacterial activity beccTABLE II ent.

Percentage	of Pore Spa	ce for	Different Soils
	(King)		
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sandy	soil		
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inution of these for	clay soil		ils will give a
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Granulation			or less then a
Clay		48.00	
dition brought about the Very f	fine clay	52 94	erven by a verial
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The pore space in any of these soils is naturally subject to considerable fluctuation, especially in the surface soil, due to tillage and the amount of organic matter present. When, however, soils are in the physical condition for the best plant growth, it will be found that the finer the soil, the greater will be the pore space.

In a soil the pore space is occupied by water and air. If the water content is low, the pore space is large and vice versa. Thus the relationship of the aggregate pore space and the size of the individual spaces to the amount of contained air and water, to their movement through the soil, to root extension, to soil aeration, to

### TABLE II

Percentage of Pore Space for Different Soils (King)

Sandy soil	32.49
Loam	34.49
Heavy loam	44.15
Loamy clay soil	45.52
Clay loam	47.10
Clay	48.00
Very fine clay	52.94

The pore space in any of these soils is naturally subject to considerable fluctuation, especially in the surface soil, due to tillage and the amount of organic matter present. When, however, soils are in the physical condition for the best plant growth, it will be found that the finer the soil, the greater will be the pore space.

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bacterial activity become apparent.

The factors which control the soil structure are plasticity and cohesion. As these increase, there is, with an excess of water, a tendency towards puddling. On the other hand, when too dry clodding will result. A diminution of these factors in heavy soils will give a better granulation of the soil particles.

Granulation is "nothing more or less than a condition brought about by the force exerted by a variable water film and the pulling and binding capacities of colloidal matter, operating at numberless localized foci. It is evident that any influence or change in the soil which will cause a greater localization of these forces will promote increased granulation." And since the optimum moisture condition of a soil for tillage is also fortunately the optimum condition for plant growth, careful attention should be paid to the effect of alternate wetting and drying of the soil, ploughing, freezing and thawing, and the addition of organic matter and lime, upon the granulation of the soil particles.

The moisture contained in the soil may be hygroscopic, capillary and gravitational. Hygroscopic moisture is the moisture which a soil dried by artificial heat will bacterial activity become apparent.

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absorb from a saturated atmosphere. Due to the absorptive capacity of the soil particles, this moisture will exist round the particles in the form of a thin film, being held partly by the surface tension of the film and partly by the molecular attraction of the moisture molecules. The amount of hygroscopic moisture increases with the total surface exposed or the fineness of the particles. Any practice that will increase the colloidal material -- the humous, colloids being very susceptible to an increase -the higher will be the percentage of hygroscopic moisutre. This is well illustrated in Table III.

# TABLE III

Hygroscopic Capac	city of Various	Soils (1)
<u>Soil</u>	Percent clay remaining in suspension after stand- ing 24 hours	Hygroscopic Water ex- pressed in percent
15 clays	31.97	10.45
7 clay loams	17.15	6.06
9 loams	12.06	5.18
5 sandy loams	7.39	2.50
4 sands	2.93	2.21

Hygroscopic water is held so rigidly to the soil particle that it is in no way available to the plant. As this zone absorb from a saturated atmosphere. Due to the absorptive capacity of the soil particles, this moisture will exist round the particles in the form of a thin film, being held partly by the surface tension of the film and partly by the molecular attraction of the moisture molecules. The amount of hygroscopic moisture increases with the total surface exposed or the fineness of the particles. Any practice that will increase the colloidal material--the humous, colloids being very susceptible to an increase-the higher will be the percentage of hygroscopic moisutre.

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2.50	7.59	5 sandy loams
18.81	8.93	4 stads in the

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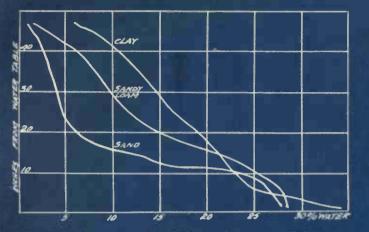
As more water is added and the film thickness round the soil grains, the outer layers are held with decreasing force, and a point is reached at which plants are able to procure all the moisture needed. At this point, according to Dr. Widtsoe, the film water is held so loosely that it moves freely from soil particle to soil particle, being termed the Lento capillary point. Above this point the water is readily available to plants and constitutes the main supply of water for plants under irrigated conditions.

Hence the following coefficients are well established (1) The hygroscopic coefficient is the percent of moisture, based on the dry weight of a soil, that a dry soil will absorb when placed in a saturated atmosphere. (2) The wilting coefficient is the percent of moisture, based on the dry weight of the soil, which remains in the soil when the plant has reached a condition of permanent wilting. increases, due to an increase in the moisture content, a thickness of moisture film is reached in which the molecular movement is perfectly free and unimpeded. These two zones, one in which capillary movement is more or less free, and the other a comparatively thin film in which molecular movement keeps the moisture attached to the soil particle, gradually merge into one another.

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FIGI

Diagram showing the distribution of maisture in appillary columns of different textures.

LYON FIPPIN BUCKMAN

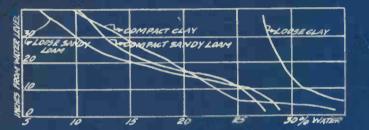


FIG.I

Diagram showing the effect of a compaction

upon the muisture distribution in capillary columns. LYON FIPPIN BUCKMAN





For successful plant growth, the moisture content should never be allowed to approach the wilting coefficient. According to the researches of Briggs and Shantz the hygroscopic coefficient is about .68 as great as the wilting coefficient or the wilting coefficient is about 1.50 times the hygroscopic coefficient.

The finer the texture of a soil, the greater is the number of angles between the particles in which a film of capillary water may be held; also, the actual amount of surface exposed by the particles is immensely larger than in a coarse soil. Due to these two conditions a soil of fine texture will contain considerably more capillary water than one of which the texture is coarse. See Fig. I.

The structure of the soil, or the arrangement of the particles, will become a factor in the capillary capacity in so far as it affects the amount of surface exposed to capillary action. Hence the granulation of a clay soil, by producing a crumb structure and by increasing the exposed surface, tends to increase its water holding capacity. On the other hand the compacting of a sand, by increasing both the effective surface as well as increasing the possible number of angles for capillary concentration, will have the same effect. See Fig. II. Organic matter has a great capilFor successful plant provin, the molature content should never be allowed to soproach the vilting coefficient. According to the researches of Friege and Shantz the hygroscopic coefficient is about .63 as great as the wilting coefficient or the wilting coefficient is shout 1.50 times the hygroscopic coefficient.

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lary capacity. Not only its porosity but also its colloidal content exerts a very high affinity for capillary water.

Capillary water moves from a wetter or thicker moisture film to a drier or thinner water film. The water will rise to a greater height on a fine textured soil tham on a coarse textured soil, although its rate of progress is much greater in the latter. Lyon and Fippin give the following Table.

#### TABLE IV

Capillary Rise in Inches for Different Lengths of Time ///

Soil	11 hr	l hr	2 hrs 1	day !	3 days	8 days		19 days
Silt and very fine sand	12.7	· · · · · · · · · · · · · · · · · · ·	7.0 2	0.0	30.0	45.0	52.0	56.0
Very fine sand	7.6	1	12.4 2	1			1	
Fine sand Coarse and medi-	19.0 11	9.5 <sup>1</sup> 1 1 1 1	10.0'1	1.6	13.0	14.3	15.2	16.0
	1	1 1	6.3 <sup>1</sup> 1	1			1	
gravel	4.0	1 5.0 <sup>1</sup>	5.3	6.4 1	8.0	9.0	10.0	10.8

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56.0	52.0	45.0	30.0	20.0		4.7		Silt and very fine sand
				1	1	1	k	Very fine sand
	1	1	10.81	1.6.11	10.01			Fine sand
			1 0.0	7.5	18.0	1	1	Coarse and medi- um sand i
10.8	10.0	0.0	0.8	¦ ¦ ⊉.∂	5.3	5.0	1 1 0.1	Fine : gravel :

With a further increase in the water content, a point will be reached when new additions of water will simply slide off the existing film and be drawn off by gravity. Dr. Widtsoe has called this point the point of maximum capillary capacity. Any existing water above this is termed Gravitational water. See Fig. III. It moves slowly downward through the pores and tubes of the soil until it is all absorbed by the lower drier soil or until it communicates with the standing water table. When gravitational water begins to appear, an adverse condition to plant growth is obtained. The proper aeration of the soil is much hampered, the roots are deprived of their oxygen and toxic materials tend to accumulate. It is therefore evident that there must be some moisture condition in a soil which is best for the development of the plants, often termed the optimum content.

The total range of available moisture does not of course represent this condition. In practice the moisture content will fluctuate considerably, forty to sixty percent of the pore space being considered essential for best growing conditions. It should be the object of every irrigator to apply just such an amount of water to his land as to bring the water moisture content as high as

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Diagram showing Seasonal variation in soil moisture percentage, Wigno alfalfa Field, Les Malines 1914. (ADAMS)

FIGTE

possible without experiencing deep percolation losses, and at such periods that the minimum water content just before irrigation does not approach the wilting coefficient. The extent to which this is achieved in practice is illustrated by the experiments of F. R. Adams on Sacramento Valley Soils. Fig. IV shows the percentages of soil moisture in a fine sandy loam soil before and after irrigation for various depths. The diagram showsthat the moisture percentage reached or closely approached the wilting point in the upper three feet of soil before each irrigation, but that it was well above the wilting point throughout the season in the third, fourth and fifth feet below the surface.

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The results of a considerable number of experiments conducted on the moisture properties of soils under field conditions of irrigation are summarized in Table V.

TABLE	V/	Harding)
-------	----	----------

Character of soil	Usual ave	erage percent	of total moist
Depth Depth 7.5 inches	'At wilt-	When irriga- tion is de- sirable	After irriga- 'tion when free 'to drain
Sandy soil	23.863	8.57 5	18.42
Sandy loam	20.73	3.81 9	17.40
Fine sandy loam	19.09	3.53 12	15.65
Loam 17.72	17.84	13:46	21
Silt loam	16.20	12.32 16	13.08
Light clay loam	15.83	11.81 17	13.14
Clay loam	15.60	12.31 18	13.22
Heavy clay loam	14:81	12.70 19	12.23
Clay	18	20	24

It is evident that, even after a heavy irrigation, the average percentage of water held in a soil to a depth of ten feet is far below the maximum capillary water content. Invariably only the top foot or often the top layer contains that quantity. With increasing depth, there is invariably a decrease in moisture content until about eight to fifteen feet, it is very little above the point of slow capillary

of total moisture	Character of soil		
After irriga- tion when free to drain	tion is de-	ing point	
8	5	3	Sandy soil
1 13	6	5	Sandy loam
18	12	9	Fine sandy loam
21	14	8	Loam
88	16	1.0	Stit losm
22	77	15	Light clay loam
22	18	14	Clay loam
23	-61	16	Heavy clay loam
24	20	1.8	Clay

PABLE V (Harding)

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.notion.

	to a depth !	Field (Wi	dtsoe) act by	sture after irrigation degistered solation percent by weight on the basis of forty
Depth	Depth	The Change of the		In the Spring
arts.	23.80	23.56	18.57	1618.42
01 <u>2</u> 7	21.88	20.73	13.81	9.4-17.49
3	20.17	19.09	-13.53	915.65
Ss4dy	17.72	17.84	13.46	1
V°5V	15.91	16.29	12.32	713.98
6	14.55	15.83	11.81	13.14
7	14.21	15.60	12.31	13.26
8	14.15	14.81	12.70	12.93

Dr. Widtsoe has termed the percentage of moisture held in field soils to a depth of eight to ten feet, with the top foot in a saturated condition, the field water capacity of a soil. In general it has been found that it does not vary very much from the optimum water content for plant growth. For various soils Dr. Widtsoe gives the following values.

TABLE VI

## TABLE VI

Table showing the distribution of moisture after irrightion (Widtsoe)

In the Spring				
	2.5 inches	5 inches	7.5 inches	
18.42	18.57	25.56	25.80	1
17.49	13.81	20.73	21.88	2
15.65	13.55	19.09	20.17	3
14.07	15.46	17.84	17.72	4
13.98	12.32	16.29	15.91	5
15.14	11.81	15.83	14.55	0
13.26	12.31	15.60	14.81	
12,95	12.70	14.81	14.15	1 8

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	GHAPTER 111	
of 8 feet The 1 water, that wi	cent by weight ret factor, influenci be considered is the	'percent by weight on 'the basis of forty 'to sixty percent 'moisture content and
Clay	1 1 1 19 19 pitation and	1625
	ther with the temperat	
	1617	
Sandy loam	ater 14.5 red for e	
Very sandy loan	shapon, and the number of	710

are applied.

The climate affects not only the total seasonal duty but is also mainly instrumental in determining the actual monthly distribution of the water requirement -a most vital factor to be considered in the design of the distribution system. The monthly requirements are controlled by the crops grown and the locality under consideration. Alfelfs or pasture in any arid region usually requires water throughout the growing season, or from early spring until late suturn, while a grain grop requires mater during not more than the first half or two-thirds of the season. Forstoes require water throughout the season, but

Registered moisture percent by weight on the basis of forty to sixty percent moisture content and thirty percent pare		Soil to a depth of 8 feet
1625	91	l 01ay
9.414	18	Clay loam
913	1617	Loam
1015	14.5	Sandy loam
710	14	Very sandy loam

27

•

## do not need it so early CHAPTER III. Orchards on the other hand then well cultivated hand little rates in the early THE CLIMATE

water, that will be considered is the Climate under which irrigation takes place.

The annual precipitation and its seasonal distribution, together with the temperature, humidity and wind movements, have a very marked and evident effect upon the amount of water required for crop production, length of irrigation season and the number of irrigations that are applied.

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#### CHAPTER III

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The following two Tables, taken from the report of Don. H. Bark are typical of the irrigated sections of Idaho. The crops and soils were divided into two classes

(1) Grain on medium clay and sandy loam,

(la) Alfalfa grain on medium clay and sandy loam.

(2) Grain on porous sand and gravelly soil,

(2a) Alfalfa and clover on porous sand and gravelly soil.

#### TABLE VII

1 -

#### Summary of Depths of Water Applied by Months to 122 Fields

of Grain on medium clay and sandy soils (12)

	-								
Season	No.of plots	April 15-30	'May 'May	June	July	'Aug.	'Sep. '1-15	'Sep. '15-30	'Total 'for 'season
An order of the	1000-00	feet	feet	feet	feet	feet	feet	feet	feet
1910	39	.00	.320	.645	.495	.095	.00	.00	1.556
1911	49	.00	1.021	.717	.428	.006	.00	.00	1.172
1912	34	.00	.000	.914	.650	.059	.00	.00	1.623
Average	o jeste	.00	1.114	.759	.524	.053	.00	.00	1.450
Percen- tage of Total	1	· .00 ·	1 17.86	.52.34	1 36.14	1 1 13.06	.00	.00	100.00

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Summary of Depths of Water Applied by Months to 122 Fields of Grain on medium clay and sandy soils (12)

		and the second second second							
Season	COUTO	00-01	1				1-15	15-30	for
		feet	teet	feet	feet	feel	feet	feet	teel
1910		00.					Service Barrier		1.556
1911	49	00.	1021	.717	.428 '	a00.	00.	00.	1,172
1918	34	00.	000.	.914	1650	980.	00.	00.	1.623'
Average	1	00.	114	.759	.524	. 053	00.	00.	1.450
Fercen-	1	1	1	1	1	1	1	t	

#### TABLE VIII

Summary of Depths of Water Applied by Months to 46 Fields

of Alfalfa on Medium Clay and Sandy Loam /12/

Sea- son	'No. 'of 'plcts	1-15	April 16-30	May	June	July			Sep.	
1910	1 17	.053	.018	.531	.720	.002	.551	.004	.000	2.54
1911	18	.00	.025	.525	.308	.945	.750	.199	.031	2.783
1912	1 11	.00	1.000	.508	.443	.697	.474	.038	.000	2.100
Aver- age	i and	.018	.014	.521	1 1.490	1 3.748	1 1.592	1.100	.010	2.50
Per- cen- tage of To- tal	i oni	1 1 1 1 1 1 1 1 1 1 1 1 1	1 1 1 1 1 1 . 56	1 1 1 1 1 20,90	1 1 1 1 1 1 19.05	1 1 1 1 1 30,00	1 1 1 1 1 23.75	1 1 1 1 1 1 1 1 1 1 1 1	.40	100.00

Irrigation water is usually applied during that part of the year which corresponds in general with the period of plant growth. The time to start irrigation is largely dependent on the initial amount of moisture present in the soil--due either to winter rainfall or fall irrigation, the available water supply and the crops to be grown. Soils which have a good water retentive power and which have been subjected to either fall irrigation or winter precipi-

### TABLE VIII

Summary of Depths of Water Applied by Months to 46 Fields

of Alfalfs on Medium Clay and Sandy Loam (ma)

Total	Sep. 16-30	Sep. 1-15	.guA	July	June	May	April 16-30	Gal the	No. of	moa
2.54	000.	.004	.551	\$00.	.720	531	.018	.053	17	0161.
2.783	.031	199'.	.750	.945	802.	. 525	.025	00.	18	1911
2.100	000.	880.	. 474	.697	. 443	. 508	000.	00.	11	1912
2.50	.010	1001.	1 1 S93.	847.	. 4903	, 521	014 <sup>1</sup>	. 018	8 9 1	Aver-
	1 1 1	1	1 ¥ 1	1 1 1	f 1 1	1 1	1	1 1 1	1	Per- cen- tage of
100.00	• 0⊉.	4 • 02 <sup>1</sup>	23.751	30.00	19.05	20.90	, 56 . 1	1 1 1 1 1	1	To- ! tal

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evident therefore that in districts where the presiditation tation, will generally be found to have sufficient initial water in the soil to start plant growth. This is due to the fact, as already shown, that the water may be stored in soils to a considerable depth as a film surrounding the soil particles. At Utah, where most of the precipitation comes in winter, it was found that in the spring most of the water that fell during the preceding winter was held in the upper eight feet (See Table VI). The quantity held in the soil varied with the percentage of water in the soil in the If the soil went into the winter in a dry condition, autumn. practically all of the winter precipitation was found in the spring in the upper eight feet. If, on the other hand, the soil was well filled with water in the fall, a relatively small quantity of the winter precipitation was found in the upper eight feet of soil. The upper couple offeet were, in both instances, fully saturated, and the percentage diminished steadily with increasing depth. Hence it is clear that when the soil was fairly completely saturated in the fall, the winter precipitation passed down beyond the eight feet limit or the root depth. From 1902 to 1907 the percentage of winter precipitation found stored in the soils in the spring--the soil going into the winter in a dry condition --varied from sixty-three to ninety-eight percent. It is

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51

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evident therefore that in districts where the precipitation comes in winter, early spring irrigation may have but little value. On the other hand, where the winters are dry and the summers wet, early spring irrigation should prove very profitable.

Porous, coarse, sandy or gravelly soils, which have but little retentive power, will require early irrigation and for new crops may even require irrigation before planting.

The effect that the rainfall, which falls during plant growth, will have depends largely on the amount of precipitation and the relative humidity of the district. It has for instance been shown in Idaho, "that a light summer rainfall has but very little influence on the Duty of water, most of it being evaporated. Heavy rains of .5 of an inch or more at a time seem to have beneficial effects, but the Idaho atmosphere during summer is so dry and the soil is so warm that lighter rains than this seem to do more harm than good, for they not only evaporate before they have had time to penetrate into the root zone, but effectually destroy any soil mulch that may have been formed by cultivation."

The beginning of the irrigation season, may in some cases, also be considerably affected by the temperature

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#### MAPTER IV

of the water. Cold water, if applied in large quantities, will lower the temperature of the soil below that which is best for plant growth. Hence if the soil has sufficient water for plants to thrive on, it will be detrimental for plant growth to apply irrigation water of a temperature below that of the optimum soil temperature.

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In an air dried soil there is a condition of equilibrium. The soluture contained has distributed itself according to the forces acting on it, in this case being primarily film forces. If the hyproscopicity of the soil is satisfied, the moisture acting under expilarity and film forces will distribute itself uniformly throughout the mass. If now this state of equilibrium is disturbed, as by the addition of water or by eveperables from the top soil, the soil moisture will tend is redistribute itself to the new conditions-bringing about thereby a movement in the soil moisture. Noisture will siveys move from the wetter to the drier soil or from the thicker to the thinner of the water. Cold water, if applied in large quantities, will lower the temperature of the soil below that which is best for plant growth. Hence if the soil has sufficient water for plants to thrive on, it will be detrimental for plant growth to apply irrigation water of a temperature below that of the optimum soil temperature.

# CHAPTER IV

MOISTURE DISTRIBUTION IN THE SOIL

It will be well, before discussing the question of the distribution of the moisture throughout the soil, to take up the question of moisture movement.

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The moisture in the soil is subjected to various forces of which the following are the most active.

(1)	GravityG.
(2)	CapillarityC.
(3)	Film Forces, such as molecular attraction, surface tension, etcF.

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If the moisture content is somewhere near/capillary point, the movement and the distribution will be primarily due to F,G and C. When the maximum retaining capacity of the soil has been reached any further addition of moisture simply slides off the already present moisture film,--neither capillarity nor film action having any hold on the water, gravity alone acting.

The lateral movement of moisture is dependent not so much on the result of capillarity, film action and gravity, but to a greater extent on the first two only. The result, as will naturally follow, is less than in the case of downward movement. Gravity will rather tend to spread the laterally moving water downward in a fan-like formation, giving thus a uniform distribution only below the topmost surface.

The upward movement of the moisture is entirely identical to the downward movement, except that in this case the action is against gravity, whilst in the former case it is aided by gravity. As the particles in the top

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surface dry out as by evaporation, there will be a gradual readjustment of the moisture particles from the thicker to the thinner films. But as evaporation is a continuous action, so too will be the movement of the soil moisture from the bottom towards the top, until the loss of moisture will be felt throughout the entire soil mass.

The problem that the irrigation engineer faces, is to be able to tell to what extent this moisture movement will take place in various types of soil or what the distribution through the mass will be. It is essential for him to know these matters, since whilst for one type of soil the water applied will wet the mass throughout the root zone, on another soil the larger portion may be lost by deep percolation, the film action and capillarity being too small to store the water. It is evident that the degree of success which the individual irrigator attains is directly proportional to his ability to grow satisfactory crops by using reasonable quantities of water.

Irrigation water which passes below the root zone of ordinary crops carries with it in solution valuable plant foods, thus tending to ultimately render the soil infertile, or, as often happens, if the downward leaching is checked by an impervious strata, a water-logged condition results, fasurface dry out as by evaporation, there will be a gradual readjustment of the moisture particles from the thicker to the thinner films. But as evaporation is a continuous action, so too will be the movement of the soil moisture from the bottom towards the top, until the loss of moisture will be felt throughout the entire soil mass.

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vouring the rapid accumulation of alkali and hastening, to a marked degree, the non-productiveness of the soil, and thereby the failure of the irrigator. Consequently the importance of gathering information concerning the depth to which soils may be wetted by irrigation cannot be overestimated.

The extent to which moisture will distribute itself after irrigation is dependent on the frictional resistance which the water has to overcome. As soon as the frictional resistance of the soil particles to the moisture becomes greater than the forces bringing about the moisture movement, the distribution will decrease rapidly and further penetration into the soil stopped. The cause of the frictional resistance becoming greater than the movement forces, must be sought in the theory that the water is gradually used up in the form of films in its downward movement. The finer the texture of the soil, the greater will be the aggregate surface exposed by the soil particles and the greater therefore will be the moisture distribution. If, therefore, a definite quantity of water is applied, it will be used up to a much larger extent in the topmost layers by the finer grained soils. A point will hence be reached where there is no longer a sufficient supply of moisture to satis-

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37

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Table IX shows the result of a laboratory experiment on sandy loam. In a glass jar some one and one-half inches in diameter a celluloid lining was tightly placed. The whole was filled with sandy loam, and sufficient water was added to give an irrigation equivalent to one and onehalf inches of water in depth. The jar was then covered with a paper to prevent evaporation. At the end of a week the soil column was taken out of the cylinder and unrolled. Samples were taken at the various depths indicated, oven dried, and the amount of water present at each given depth, calculated. Table IX shows the results obtained.

tribution in the part of the curve AB, and the abrupt deeline of penetration after the point b has been passed. Similar experiments conducted through a longer period show that with an increase in time the moisture distribution followed roughly in the way indicated, always converging towards the coint c.

These conditions are not necessarily met with in field practice, the part be of the curve having been forced down to a much greater depth by either the rainfall or exfy the wants of film action, frictional resistance will increase rapidly and the distribution of the molsture diminish abruptly

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the distrib	ution when the	soil is in	an air dre gondi tion
surface in	present	ficient	Net capillary water tending to distribut
the moistur	14.35	2.04	ld be peid to lighte 12.31
irrigations 2	12.97	2.04	10.93
within the 3	14.13	2.04	12.09
depth by ex	13.63	2.04	11.59
5 tent be dep	15.03	2.04	14.99
6	13.22	2.04	11.18
resistance	11.88	2.04	9.84
and the shr	9.04	2.04	7.60

TABLE IX, shundantly clear that

The results show a very uniform moisture dis-

tribution in the part of the curve AB, and the abrupt decline of penetration after the point b has been passed. Similar experiments conducted through a longer period show that with an increase in time the moisture distribution followed roughly in the way indicated, always converging towards the point c.

These conditions are not necessarily met with in field practice, the part bc of the curve having been forced down to a much greater depth by either the rainfall or ex-

39

The second second second second second second second	and and an annual sector rando	and the second s	and the second s
	Hyg. coef- ficient	Percent water present	
12.31	2.04	14.35	1
10.93	2.04	12.97	S
12.09	2.64	14.13	3
11.59	2.04	15.63	4
14.99	2.04	15.05	5
11.18	2,04	13.22	9
9.84	2.04	11.88	4
7.60	2.04	9.04	8

TABLE IX

The results show a very uniform moisture distribution in the part of the curve AB, and the abrupt decline of penetration after the point b has been passed. Similar experiments conducted through a longer period show that with an increase in time the moisture distribution followed roughly in the way indicated, always converging towards the point c.

These conditions are not necessarily met with in field practice, the part be of the curve having been forced down to a much greater depth by either the rainfall or excessive irrigation. But it is abundantly clear that the distribution when the soil is in an air dry condition stops at a very marked depth, where the frictional resistance becomes greater than the forces tending to distribute the moisture. Greater attention should be paid to lighter irrigations so that the total distribution abcd may be kept within the root zone, rather than forcing it beyond that depth by excessive applications of irrigation water.

The frictional resistance will the a large extent be dependent upon the initial amount of water present. The greater this amount, the smaller will be the frictional resistance and the greater will be the downward penetration, and the abrupt change in moisture distribution. It is a matter of common experience, the farmer finding that the water does not penetrate the soil deeply during the first year of irrigation; but, as time goes on, the soil becomes wetter to greater depths, and at the same time less water is required by his crops.

The moisture content of the native undisturbed soil in arid regions is usually below the point of lento capillarity. The first water added is used to bring the moisture content up to this point, and as this is accomplished, water moves downward freely; the plants being enabled to secure their water supply with a corresponding cessive irrigation. But it is abundantly clear that the distribution when the soil is in an air dry condition stops at a very marked depth, where the frictional resistance becomes greater than the forces tending to distribute the moisture. Greater attention should be paid to lighter irrigetions so that the total distribution abed may be kept within the root zone, rather than forcing it beyond that

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smaller expenditure of energy. At the Experimental Farm at Davis the results obtained are given in Table X.

laboratory. Is there then for every soil a definite quan-									
Depth	naties	.5	1.5	2.5	3.5	1 4.5	5.5	Dry at	-
Percent Moisture ovendried basis	on	i je plar i	1 167 21	is 🕬	dll to	o ear)	y in i	of maxi hese in- nt, to a	
Boring	I	21.05	18.16	15.33	17.04	20.48	14.29	6 ft.	
Boring	II	20.49	20.39	19.06	19.04	23.19	14.74	5.9 ft.	1
Boring	III	20.55	17.92	16.04	18.19	13.26	12.55	6.4 ft.	

more the mechanical application of the water in field prec-

check, the skill of the irrigator and so many other mechan duty realized. Even if it were possible to apply water in such quantities as would be best from the preceding con smaller expenditure of energy. At the Experimental Farm at Davis the results obtained are given in Table X.

Depth .5! 1.5! 2.5 2.5 5.5' 4.5' 5.51 Dry at Percent Moisture on 1.1.1.1 beltibrievo basis I'21.05'18.16'15.35'17.04'20.48'14.29' 6 ft. Boring II '20.49 '20.39 '19.06 '19.04 '35.19 '14.74 ' 5.9 ft. Boring Boring III 20.55 17.92 16.04 18.19 13.26 12.55 6.4 ft.

TABLE X

These results were obtained under typical field practice conditions, the samples being taken in an orchard.

The results closely follow those obtained in the laboratory. Is there then for every soil a definite quantity of water which will distribute its moisture uniformly throughout the soil mass to just a sufficient degree and depth to prevent any deep percolation loss and be of maximum use to the plant? It is still too early in these investigations, which are being carried on at present, to arrive at any definite conclusions. One fact is however apparent, that whilst we may increase the duty of water very considerably from purely scientific considerations, it is more the mechanical application of the water in field practice which retards the obtaining of any such increased efficiency of the water. The tremendous waste, due to the improper levelling of the land, the loss at the head of the border or check, the waste at the end of that border or check, the skill of the irrigator and so many other mechanical factors are the more responsible elements for the low duty realized. Even if it were possible to apply water in such quantities as would be best from the preceding considerations, it will always be the mechanical factors to

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The California Branch of Irrigation Investigations of the United States Department of Agriculture has, in co-operation with the State Engineering Department and the Agricultural Experimental Station at Davis, studied during the past three years the distribution of irrigation water in various soils. Observations of the results, which may be regarded as those of typical irrigated soils, will be presented. The observations were made under two somewhat distinct conditions. First, studies were made upon various farms in the Sacramento River Valley, on fields producing alfalfa (lucerne). Soil types representative (according to the Bureau of Soils U. S. D. A.) of extensive areas in the valley, were chosen. The other conditions are those at the University Farm at Davis, where alfalfa was grown upon one-fourth acre square lots. The surface two feet of soil is a loam of remarkable uniformity, and the third to eighth foot sections consist of a sandy loam of recent origin, pocketed at irregular intervals with coarse sand or clay loam. This fine sandy loam lies upon an undulating clay which extends from nine feet to a depth of twenty or more feet below the surface.

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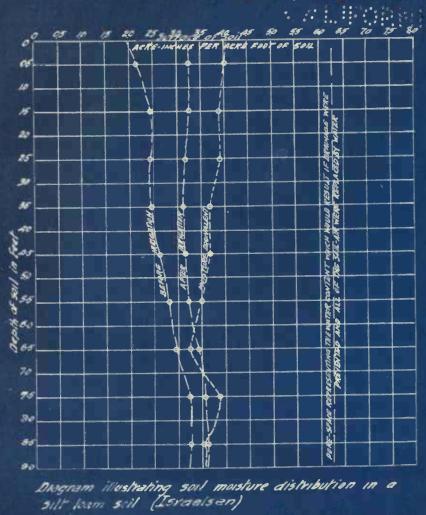
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## Sacramento Valley Experiments

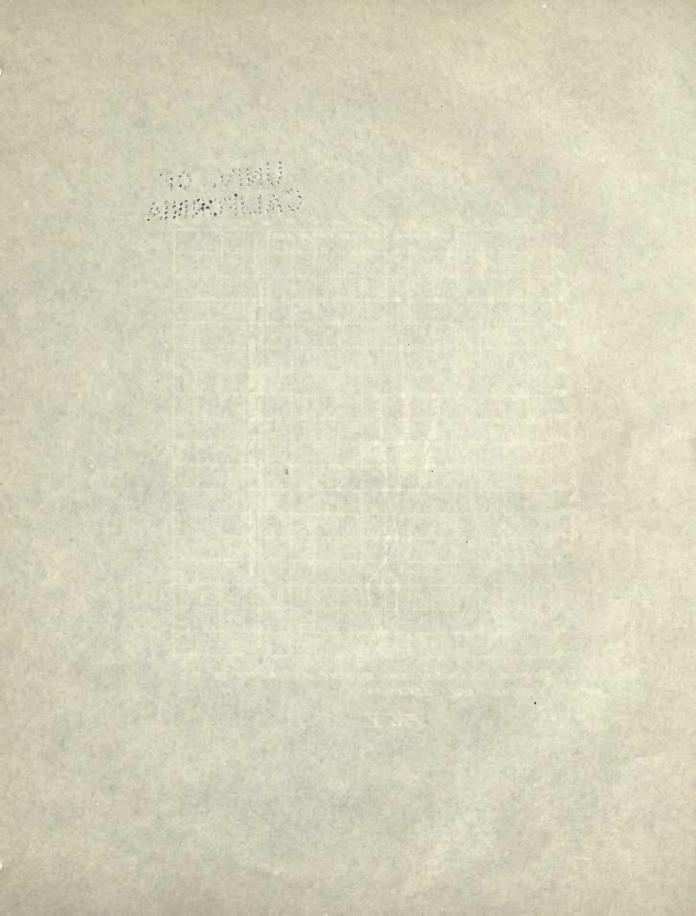
Silt Loam Soils. In Table Xi and Figure V are presented results of moisture determinations upon three tracts, classed as silt loam soils, which are based upon one hundred thirty-eight six feet and thirty-six nine feet borings. The curves of the silt loam soils converge gradually from the surface of the soil downward. This may be due to a large extent to the fact that these soils do not dry out as rapidly at great depths as to the more porous sandy loam soils. The average amount of water held after irrigation was 3.20 inches per foot, or enough to fill fifty-one percent of the pore space.

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FIGY



			+					
.35 5.48	.48 .40	53 .49	.66	.72	.81	1.04	set.	Increase
.56 3.62 30.55	3.31 3.42 3.56	23 3.31	.26 3.23	32 32	38'3.45'3.	13.38	69	After Irrigation
.16 3.27 25.07	82 2.94 3.16	70 2.82	.60 12.	34 2.64 2.60 2	2.64	2.34	. 69	Before Irrigation
	he i	owa						Averages
.31 5.67	.54 .31	60 .60	.63	.67 .	.86	1.15		Increase
3.09 3.26 3.30 3.35 28.64	13.26 3.30	04 3.09	3.00 3.04	3.04 3		3.27 3.29	45	After Irrigation
2.37 2.37 2.44 2.49 2.72 2.99 3.04 22.97	2.72 2.99	44 2.49	.37 12.	2.37 2	2.43	2.12 2.43	45	Before Irrigation
	5 per 5 per	11 To	4.05	4,01 5,27	0 fe	6 aor		Hofhenke,Los Molinos
2 .40 4.83		45 .41	.68 .	.77 1	.76	.96		Increase
3.50 3.62 3.01 3.52 3.42 3.53 3.57 3.82 3.90 32.49	5 3.57 3.82	42 3.53	.52 3.	3.01 3	3.62	3.50	1 24	After Irrigation
· 50 3.50 27556	2,61	2.54 2.86 2.84 2.84 2.97 3.12 3.	.84 2.	2.84 2	12.86	2.54	24	Before Irrigation
	100	tota	85 - 81	25		eree		Bundy,Los Molinos
	t be							ples were taken
depth		of Soil	Foot				ples	1
Acre Inotal wa-	nch per	Acre		e Content	Moisture	0110		Tract treatment and time of Samples
	ie on							
		(17)	TABLE XI SILT LOAM/17/	TABLE SILT 1				
	-			C			_	

fine of Samples	Dopth at which cam	Enugh for Molinon	Before Intigation	noiteriral refly	Increase	aou, annonton Bontlow	Deloie Init ation 1	After Irrigetion	THOMENER	A LECES	02	I ROLF BLATI	Increase 1
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tustio)			53 - 64 64	10			10.5	10		-	· · · · · · · · · · · · · · · · · · ·	33.6	99.
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0			06.0	00.61	4		- 2.04	53 53 53 53 53 53 53 53 53 53 53 53 53 5	8			· · · · · · · · · · · · · · · · · · ·	93 10
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In the case of the Bundy tract, four irrigations were given of 17.22, 12.20, 11.55 and 7.77 acre inches per acre respectively. The moisture determinations indicating that the following amounts were retained in the upper six feet.(IB)

		Percent acre inches per acre retained on top 6 feet		re-'Percent 'lost
-	17.22	4.01	23	77
	12.20	oh too 3.27	27	1 73
lation	11.55	4.03	35	65
	7.77	4.73	61	1 39

The Table shows that in this case for a total depth of nine feet only 5.13 acre inches per acre was retained or 44.4 percent of the total, 55.6 percent being lost beyond the root zone. In the Hofhenke tract, the following additional results were obtained. (18)

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	re-Percent 10st	Percent teined	Percent acre inches per acre retained on top 6 feet	rucues per sere
-	1 77	1 25	4.01	17.22
	1 73	1 27	5.27	12.20
	1 65	35	4.03	11.55
	1 39	61	4.75	77.7

The Table shows that in this case for a total depth of nine feet only 5.13 acre inches per acre was retained or 44.4 percent of the total, 55.6 percent being lost beyond the root zone. In the Hofhenke tract, the following additional results were obtained.//8/

Acre inches applied per acre per irriga- tion	Acre inches per acre retained in the upper 6 feet	tained	Percent lost
18.76	5.42	1 1 29	71
15.74	3.78	24	76
18.86	5.36	28	72
13.22	3.50	26	74

The results show the obvious fact that the quantities applied were much too great, the losses by deep percolation being in all cases excessive.

fercent lost	Percent re- tained	Acre inches per acre retained in the upper 6 feet	Acre inches applied per acre per irriga- tion
1 1 71	29	5.42	18.76
י י 76	24	5.78	15.74
57	28	5.36	18.86
74	26	8.50	13.22

46

1.1.

The results show the obvious fact that the quantities applied were much too great, the losses by deep percolation being in all cases excessive.

TABLE XII CLAY LOAM SOILS/17/

(

Averages Before Irrigation	Guile, Woodland Before Irrigation After Irrigation Increase	Geer, Los Molinos Before Irrigation After Irrigation Increase	0'Hair, Orland Before Irrigation After Irrigation Increase	es were	t, lo of s
87	122	488	27	ft.	No. of samples
2.10	2.23 4.00 1.77	2.60 3.67 1.07	1.46 3.14 1.68	Сл	Moi
01 22 72 23 72 23 72 72 23 72 23 72 72 72 72 72 72 72 72 72 72 72 72 72	2.46 .88	3.06 80	1.83 2.51 .68	1.5	sture C per A
2.38 528 52	2.60 58	2.40	2.40	2.5	ontent cre Fo
3.60 400	3 N    	2.44 3.17 .73	2.69 .03	3.5	in Acr
2.87 3.20 .33	2.74 3.20 .46	2.06 3.27	8.22 123.52 123.52	<b>4.</b> 5	e Inch
2.97 3.28 .51	2.72 3.18	2.67	3.51 3.44 .07	5.5	0 0
15.35 19.19 3.84	15.42 19.12 3.50	15.83 20.25 4.42	14.77 17.41 2.64		Total

The the set I

# OTVI TOWN DOITPNAN

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actinol.ce	01.05	4141		
. Note	24.14 1.55 1.69 1.69	09-8 70-1	28.60 00.4 00	8-20 2-20 7-20
Fr2	7 8 8 9 8 9 8 9 8 9 8 9 8 9 8 9 8 9 8 9 8	50.3 08.3 08.3	아 80 41 년 80 10 41 60	53-87 - 45-55 - 55-56 - 55-66 - 55-66
Content Acre 200	0 0 2 48	5 80 4100 4100	691.0 61.0 61.0	200 00 200 00 200 00 200 00
to here	88.05 69.55	で 1997 1		000.00 000.04 0000
01.10	250 0100 710	010	61 20	0000 0000 0000 0000
0.0	80 R 240 140	57.27 5.27 5.27	010 10 10 10	82.5 82.5
loici	74. CV	30.55 15.98 15.99 15.98 15.99	72.50 75.48	23.31 19.19 19.19

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- 1 - 1 - 1

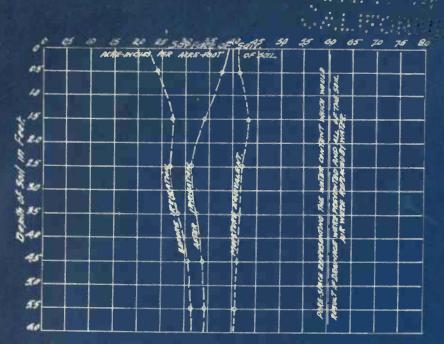


Diagram illustrating the soil maisture distribution in a clay learn soil (Israelsen)

FIG YE

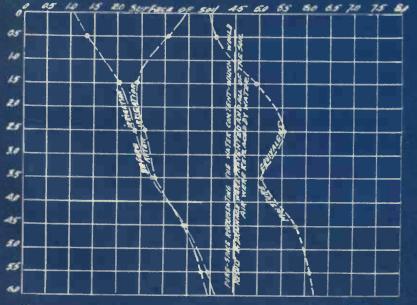
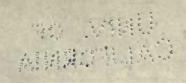


Diagram illustrating the sal moisture distribution in a clay soil. [Israelsen]

FIGYT



## Clay Loam Soils

In Table XII and Figure VI are given the quantities of water held before and after irrigation on a number of farms having typical clay loam soils as determined by two hundred ninety-six six feet borings. The Figure represents the average results. The increase in moisture varies from 1.35 in the surface to .28 in the sixth foot, as compared to a variation of 1.13 to .44 in the silt loam soils. The increase in vonvergence of curves with depth as the texture of the soil increases in fineness is apparent. The water content decreases appreciably after irrigation with the depth of the soil. It is therefore doubtful if the maximum capillary capacities of these soils were satisfied. The average amount of water held by the clay loams after irrigation was 3.49 inches per foot or enough to fill fifty-eight percent of the pore space as compared to fifty-one percent in the case of the silt loam. ount of moisture in the soil before.

this type of soils. (18)

to nine feet below the surface.

penetrated below the sixth foot. At the time of the first cutting the relature content of the soil was so low, that

## siles mod Tale

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The following additional recults are given bo

Farm 'Irrigation in 'acre inches 'per acre	acre retained	retained	pproximited
0'Hair 6.24			
of the init 3.18 moun			
emount of 13.24al mo			
Guile Leta 7.28 and			
other ind 5.94 great			
Geer 1 24.00 will			
subsequent 18.19 tions			
12.15	y at 5.37 resu	44.	36
Table 1 124.34 ge a			

t deep) in the case of the Room treat in

A striking condition was obtained in the case of the O'Hair field in that, while the percentage of the irrigation water applied retained in the soil decreased with the depth, the amount of moisture in the soil before irrigations actually increased with the depth, apparently due to the capillary use of ground water, which stood seven to nine feet below the surface.

In the case of the Guile field, very little water penetrated below the sixth foot. At the time of the first cutting the moisture content of the soil was so low, that

taod	Percent	Percent retained	Acre inches per acre retained in top 6 feet	acre inches	
1	43	57.	3.58	6.24	O'Hair
	34	.00	2.1l	3.18	
	34	. 66.	2.14	3.24	
	45	55.	4.03	1 7.28	Guile
	6	.10	5.41	5.94	
	77	23.	5.59	24.00	Geor
	82	18.	88.8	1 18.19	
	36	44.	5.37	1 12.15	
	85	1 15.	3.76	1 24.34	

A striking condition was obtained in the case of the O'Hair field in that, while the percentage of the irrigation water applied retained in the soil decreased with the depth, the amount of moisture in the soil before irrigations actually increased with the depth, apparently due to the capillary use of ground water, which stood seven to nine feet below the surface.

In the case of the Gulle field, very little water penetrated below the sixth foot. At the time of the first cutting the moisture content of the soil was so low, that nowhere in the upper six feet was it much, if any, above the wilting point. The same conditions were approximated at subsequent irrigations. This no doubt accounts for the large percentage retained, showing again the influence of the initial amount of water present. The smaller the amount of initial moisture present the greater will be the amount retained and kept uniformly distributed. On the other hand the greater the amount of initial moisture present the greater will be the downward penetration of any subsequent additions of water.

Another very striking result from the above Table is the large amount lost beyond the root zone (assumed to be six feet deep) in the case of the Geer tract. This is unquestionably due to the large amount of water used, which should not be mistaken for a large head of water. It is but logical, that once sufficient water has been applied to satisfy the capillary capacity of the soils, any further addition of water will increase that amount which penetrates past the sixth foot in depth, decreasing thereby the percentage retained.

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In c in times 11 to apply its of which i surface high, to j id 24.54 pc	Averages Before Irrigation 43 After Irrigation 43 Increase	Tuttle Willows Before Irrigation 19 After Irrigation 19 Increase	Purdy, Willows Before Irrigation 24 After Irrigation 24 Increase	Depth at which sam- ' ples were taken ' ft	Tract, location and No: of time of sampling 'sample	
persent c both befor The Fible XII a feet bor unings. I that the c	1.35 3.06 1.71 1.71 2.58 2.41 2.58 2.41 2.58 2.04 2.58 2.04 2.58	1.40 2.09 2.70 2.65 .61 .29	1.30 3.03 1.99 2.39 2.39 1.73 .12 .12		CLAY SOILS // 7/ Moisture Content per Acre Foo	TABLE XIII
e irrigati ity of the 14 after 1 64.5 percent opt molet i tor, but e	2.73 3.44 3.92 15 2.80 3.42 3.79 18 .07 .02 .13 2	2.64 3.46 3.48 15 2.81 3.29 3.52 18 .17 .13 .04 2	0000	3.5 4.5 5.5 0-6	ln Acre Inch t of Soil	
pillary and The s	N B 5 N B 5 N N B 5 N N B 5 N N B 5 N N B 5 N N B 5 N B 5 N B S N B	8.93 2.93	1004	ი ყ ლ	Total	

IVBTE XIII

## CIEX SOILS WAY

Tract, location and time of sampling	oldw d let of	Increase	e M ere	Averages Defore Invigation After Invigation Increase
no. of semples	2. 2. 2.	03 03 41 41	Ч0 Т0	4+ 4+ 10 10
d a how		7.02 7.20	1.40 1.40	7.00 7.00
per Acre	J.D	4.99 2.12 2.12	60.S 10.S	S S
I dree	CS TO	55 20 20 15	800 800 601 00 801	88 88 88 88 88 88 88 88 88 88 88 88 88
aroA n of To	60 10	800 804 80 80 80 80 80 80 80 80 80 80 80 80 80	88. 89 4	27.3 70.5
Tion 1	4.0	22.03 N. N.	80 80 40 80 80 80 80 80	82. 448 448
	12.5	4.4.20	10 0 4 10 0 0 0 4	0000 0100 0100 0100
Total	10-0 EF	7.48 78.02 70.57	18.45 18.45	18.00 15.00

## Clay Soils

In clay soils the maximum water holding capacity is sometimes limited by the pore space. This condition seems to apply to the soils described below, the volume weights of which were found to be very high. The total external surface area of these soils is in all probability very high, to judge from their mechanical analysis, which showed 24.54 percent of total sand, 40 percent silt and 34.84 percent clay. Yet the quantities of water found in them both before and after irrigation were extremely low.

The observations made upon Clay soils are presented in Table XIII and Figure VII. Figure VII is based upon 86 six feet borings and Figure VII contains the averages of 568 borings. The Table reveals at a glance the striking fact that the surface foot of soil was appreciably moistened by the irrigation water. It is doubtful if the capillary capacity of the wetter section was entirely satisfied; yet it held after irrigation 3.06 inches of water or enough to fill 64.3 percent of its pore space. The sixth foot, which was kept moist by the ground water table, contained no gravity water, but eight-six percent of its pore space was occupied by capillary water, leaving only sixteen percent of pore space.

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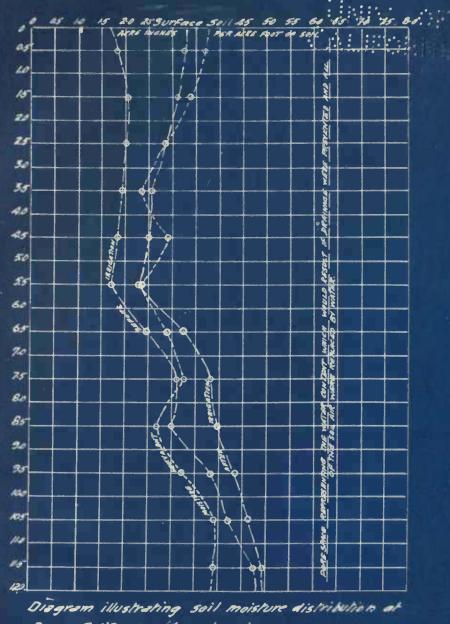
season. Of the 7.08 inches in depth applied in the first irrigation about twelve percent entered and was retained in the upper three feet of soil, of which about eleven percent was in the upper foot. In other words, practically no moisture penetrated below twelve inches. In the second irrigation a depth of 4.56 inches was applied, nearly all of which penetrated the soil and of which about forty-five percent remained in the upper foot. In the third irrigation a depth of 4.80 inches was applied, of which approximately one-third remained in the upper foot, with no increase below the second foot. The moisture determinations before and after the fourth and last irrigation, when a depth of 3.84 inches was applied, indicated that the soil became more impervious to water as the season advanced, for about sixty-six percent of the amount applied was retained in the first foot, with no significant increase below that.

The soil of the Tattle field is similar to that of the Purdy field, but slightly coarser in texture and a little more open and permeable. Moisture determinations were made from ten borings before and after irrigation the second irrigation and nine before and after the third irrigation, a depth of 4.08 inches being applied in the first case and 4.16 inches in the second and third irrigation. At

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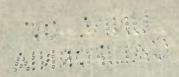
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the second irrigation ninety-three percent of the water applied was found to enter the first three feet of soil, about one-half being retained in the first foot. In the third irrigation forty-four percent was retained in the first six feet, three-fourths of which remained in the first foot. the second irrigation ninety-three percent of the water applied was found to enter the first three feet of soil, about one-half being retained in the first foot. In the third irrigation forty-four percent was retained in the first six feet, three-fourths of which remained in the first foot.



Davis, California. (Israelsen)

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TABLE XIV

IrrigationTime of No. of 'Sampling 'samples'Moisture content in acr Moisture content in acr $1 - 1 - 1 - 1 - 1 - 1 - 1 - 1 - 1 - 1 -$	5.5
ples were taken       feet       .5       1.5       2.5       3.5       4.5         26 inches 'Before Ir'       ''	.13
26 inches Before Ir 'rigation' 14 '1.78 '2.03' 2.14' 2.46' 2.37'2 Plot B 'After Ir- 'rigation' 14 '3.26' 2.99' 2.86' 2.69' 2.73'2	.13
26 inches Before In- 'rigation' 14 '1.78 '2.03'2.14'2.46'2.37'2 Plot B 'After Ir- 'rigation' 14 '3.26'2.99'2.86'2.69'2.73'2	
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	· 1.0
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rigation 21 1.68 1.93 1.91 1.80 1.43 1	.29
Plot C 'After Ir-' 'rigation' 21 '3.34 '2.99'2.82'2.45'2.10'1	.86
Increase   1.66   1.06   .91 .65 .67	. 57
46 inches 'Before Ir' ' ' ' ' '	1
rigation 28 1.76 2.06 2.06 1.87 1.59 1 Plot D After Ir-	.49
'rigation' 28 3.30 3.06 2.75 2.26 2.02 1	.87
Increase 1.54 1.00 .69 .39 .43	.38
4-7-5inches Before Ir	0
'rigation' 28 '1.95 '2.16'2.08'1.85'1.73'1 Plot E 'After Ir-	.63
'rigation' 28 '3.20 '3.16'2.95'2.60'2.40'2	
Increase 1 1.25 1.00 .87 .75 .67	. 56
49 inches 'Before Ir-!	6
'rigation' 28 1.85 2.04 1.92 1.76 1.87 1 Plot F 'After Ir-'	.59
'rigation' 28 '3.17 '3.10' 2.82' 2.52' 2.57'2	.34
'Increase' 1.32 '1.06' .90' .76' .70'	.75
4-12 inches 'Before Ir-'	
'rigation' 28 '1.91 '2.18'2.05'1.96'2.11'2 Plot G 'After Ir-'	.32
'rigation' 28 '3.24 '3.30' 3.04' 2.99' 3.23'3	
'Increase' 1.33 '1.12' .99' 1.03' 1.12'	.09
Averages 'Before Ir'	-
'rigation' 147 '1.82 '2.07'2.02'1.95'1.85'1 'After Ir-	.74
rigation 147 3.25 3.10 2.87 2.58 2.51 2	
'Increase' 1.43 1.03 .85 .63 .66	.57

[nches	per a	cre Fo	ot cf	Soil		Total ter a Depth	at	Total percent- age of water retained	
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4.22	3.77	3.76	4.32	4.32	4.92	'19.21 ' 6.68	44.52	21.5	itational wa
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## Experiments at the Agricultural College at Davis

The amounts of water held at each foot of soil before and after irrigation and the average increase which were found for the various applications are set forth in Table XIV and Figure VIII. The soil of plot B being finer in texture than that of plot D, especially below three feet, accounts for the higher water content both before and after irrigation. Variation in the soil of plot B is probably the cause of an apparent discrepancy in the relative amounts of water accounted for. A comparison of plots C and D indicates that plot C became drier before irrigation than did plot D, which accounts for the greater amount of water being retained by plot C since each plot contained about the same quantity after irrigation. In plots E and G the upper six feet were moistened to their full capillary capacity. It is likely that the clay loam stratum of the seventh foot in plot G by retarding the downward movement caused some gravitational water to be held in the fifth and sixth foot sections till the time of sampling. The effect of the large irrigations of plot G is evident in the great difference between the moisture contained, before and after irrigation, in the

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third to sixth foot sections. The twelve inch irrigation of plot G caused slightly greater increases than the nine inch application of plot F in the second to seventh foot. The upper six feet of the water content curve

in Figure VIII plotted from the averages in Table XIV are based on 294 borings; the section seven to nine feet is based upon 120 borings and the depth from nine to twelve feet represents averages of 48 borings. Adams summarizes the results obtained as follows: //8)

> "Not counting the experimental plots at Davis and Willows, moisture determinations were made chiefly on 15 fields, of which 13 were of silt loams or clay loams. In the case of all but one of these loam soils, for which one the full capacity of the soil to retain water was not satisfied, the average quantity of irrigation water retained per irrigation in the upper six feet of soil was equivalent to a depth of only 4.31 inches, or only 32.6 percent of the average individual applications, and only .72 acre inch per acre per foot in depth of the soil. Although the roots of the alfalfa penetrate in these soils to a greater depth than six feet, it is plain that a considerable portion of the irrigation water went below the zone of greater root activity and was largely or wholly wasted.

Considering the quantities of irrigation water retained in the upper six feet of soil for all of the field for which soil moisture determinations were made, it is found that the average quantity retained in the lighter and more permeable soils was .92 acre inch per acre for each in depth of soil, whereas the clay soils absorbed an average of only .37 acre inch per each acre foot of soil, or at the rate of only third to sixth foot sections. The twelve inch irrigation of plot G caused slightly greater increases than the nine inch application of plot F in the second to seventh foot. The upper six feet of the water content curve

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Averaging the quantities of irrigation water retained by each field for which moisture determinations were made, it is found that the maximum quantities retained per acre foot of soil per irrigation were 1.02 acre inches for the silt loams with fine sandy subsoils, .75 acre inch for the silt loams without fine sandy subsoils, .78 acre inch for the clay loams and .49 acre inch for the clays.

Considering only the moisture determinations from the surface foot of soil of the 15 farms, it is plain that, in the case of the typical silt loam soils of the Sacramento Valley, single applications of irrigation water, exceeding depths of one to one and one-half inches per foot in depth of soil it is necessary to moisten, accomplish no useful purpose. While the typical clay loams and clays of the valley will retain against gravity in their normal growing condition as much as 12--1 3/4 acre inches of irrigation water per acre foot of soil, over and above the amount normally found in such soils under Sacramento Valley field conditions, that amount of irrigation water will not be absorbed by these soils unless it is applied very slowly.

The wilting percentages for the Sacramento Valley soils under investigation ranges from 10.35 in the case of the silt loams of the experimental irrigation tract on the University Farm at Davis, to 16.59 in the case of clay loam on the same tract. The average wil-

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ting percentages for the several types of soil under observation were 10.65 for the silt loams with fine sandy subsoils, 13.12 for the other silt loams, 14.21 for the clay loams and 13.06 for the clays. The approximate quantities of water necessary to apply to thoroughly dry soils of the types listed to bring the moisture content up to the wilting points given are in inches in depth per foot of soil, 1.5 for the silt loams with fine sandy subsoils, 2 for other silt loams, 2.3 for the clay loams and 2.6 for the clay. The optimum percentage of available soil moisture for Sacramento Valley alfalfa soils over and above the percentage at which wilting occurs, seems to average between 4 and 6%. This is equivalent to depths of from .6 to .9 inch of irrigation water per foot of soil for loam soils and of from .7 to 1.2 inches per foot of soil for the heavier clay loams and clays.

Alfalfa planted on very open and very impervious soils should be irrigated more than once between cuttings. This is necessary in the case of the open soils because of the inability of such soils to retain all of the moisture needed to mature a crop, and in the case of the impervious clay soils in order to accomplish deeper penetration of the irrigation water into them. In case of the latter soils it is very desirable that the moisture supplied by winter rains shall be supplemented by irrigation water sufficiently early in the spring to prevent drying out. The frequent use by irrigators on such soils of a soil auger is to be urgently recommended, the investigations having demonstrated that penetration of irrigation water into the clay soils is very much less than irrigation usually realize.

It will be noticed that the curves plotted from the foregoing result do not bear the same character-

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istics of an abrupt diminution of soil moisture at a fairly definite depth as the experiments quoted previously did. The explanation of this is to be found in two factors. In the first instance the initial water content, especially at the lower depths, is much higher than in the first case, where practically air dried soil was used. This will have the effect of decreasing appreciably the frictional resistance that the irrigation water has to overcome in its downward penetration, since the initial water distributes itself as films round the soil particles. The water that is added therefore is under a much smaller influence of soil affinity and the other film forces. There is therefore a greater tendency towards the sliding off from the already existing water films. The higher the initial percentage of water present the greater is the amount that will penetrate downward.

In the theoretical diagram, if the initial water percentage is kf, the amount of water that will be distributed uniformly is cde, whilst if the initial percentage is kg, the excess amount of chj--and the resulting curves before and after irrigation will be as shown--the two curves converging with an increase in depth. In view of the results obtained from these experiments and the assumed

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There is a very mistaken fallacy abroad (especially is this the case in alfalfa) that the soil should be wetted to the depth of the roots, and alfalfa being deep rooted, sufficient water should be applied to penetrate to that depth. But since it is a well known fact that the roots rather distribute themselves according to the prevalent moisture, it follows that any excess water specially applied for deeprooted plants, say below the sixth foot, is practically an entire waste. It has been noted by various authorities that on an average the following percentages of the entire root system for alfalfa penetrate to the depths indicated.

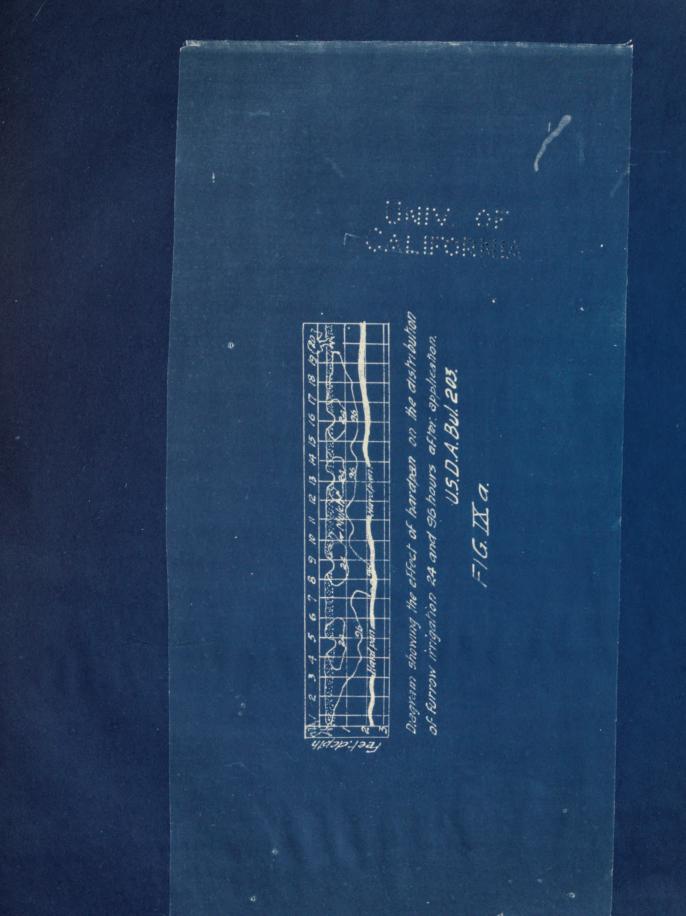
	1	foot	deep	27	percent
	2	feet	H	43	R
	3	Ħ	н	12	Н
	4	U	н	10	H
	5	H	H	7	H
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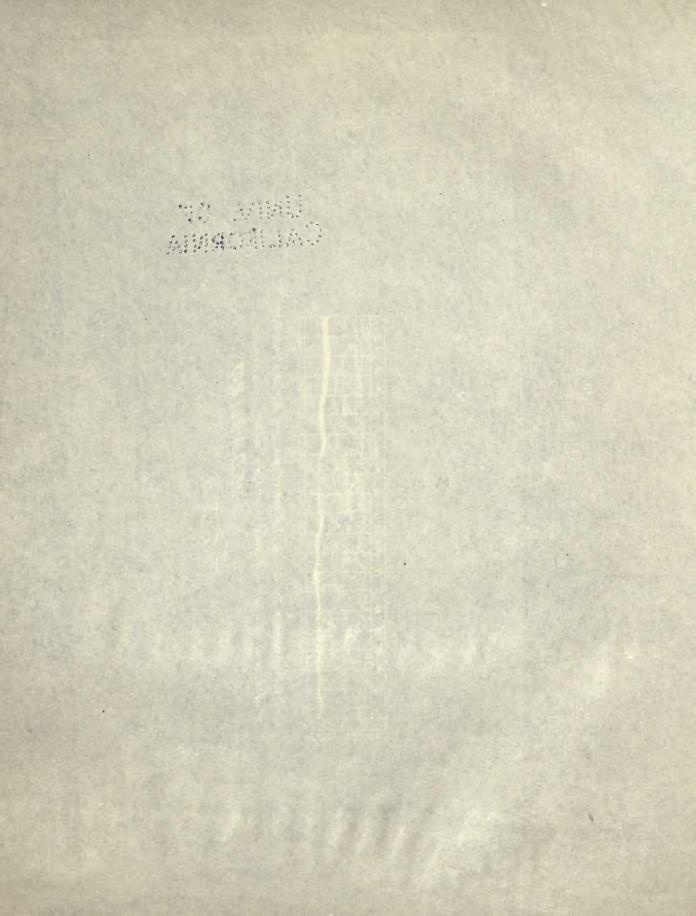
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percent	27	deeb	jooj	E	
n	43	w	feet	S	
9	12	H.	11	3	
u	10	н	11	4	
n.	7	9	H	5	
в	I	w	U	5	beyond





# CHAPTER V

### CHARACTER OF SOIL AND SUBSOILS

Apart from the actual texture and structure of the soil, there are various conditions that are met with which influence the application of water to a very large extent. Foremost of these is the layer of hard consolidated soil particles, known as hardpan. See Fig. IX.

Hardpan is the result, to a large extent, of soil weathering. The finer the particles are broken up, the nearer do they approach that class of soil termed clay. The particles are subjected to percolating water, and the soluble constituents may be taken into solution. Thus we have solutions of sodium carbonate and various silica salts, associated more or less with other products of rock decomposition. It is in the surface soil that these solutions are chiefly formed. And according as their descent into the substrata is unchecked, or is liable to be arrested at any particular level, whether by pre-existing close grained layers or by the cessation of the rainfall, the subsequent penetration of air and evaporation of the water alone by shallow rooted plants, may cause the accumulation of the dissolved matter at a particular

#### V and and a

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According to the cementing agent, hardpans will either be an iron, lime or siliceous hardpan. The iron hardpans are exceedingly heavy and much more compact than the lime hardpan. It has the fortunate characterictic that when once broken up by dynamite or some other method, there is but small danger of it reconsolidating. On the lime other hand/hardpan, which is readily recognized by its lighter colour and by its rapid disintegration by dilute

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acid, may be reformed by the descending water in time to a second hardpan layer. The iron and silica salts, once precipitated out, do not readily redissolve.

It is fairly well established that the lessen the rainfall, the smaller the depth at which hardpan is found and the softer in texture it probably will be. In general, hardpan may be encountered from twelve to twentyfour inches below the surface. If at a greater depth, it will usually be due to the formation of a more recent soil layer on top of the original surface.

It is evident that when such an impermeable layer is allowed to remain near the surface it produces serious results.

(1) By the failure to absorb the greater part of the water, thus permitting it to flow to the lower part of the orchard and out into the adjoining lands, (2) by facilitating sideway surface percolation from the furrows and exposing a greater area to evaporation by the heat of the sun, (3) by holding the water near the surface and thus causing its loss by evaporation before the soil is cultivated, (4) by preventing access of the water to the roots of the trees, if any, lying below the hardpan, (5) by preventing proper ventilation and aeration of the subsoil. acid, may be reformed by the descending water in time to a second hardpan layer. The iron and silica salts, once precipitated out, do not readily redissolve.

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Soils underlaid with hardpan should therefore be irrigated very continuously -- a more moderate quantity more frequently applied than for deeper soils being the best practice. It may often be profitable to blast occasional holes through the hardpan to serve as outlets for the excess water that stands on the hardpan. Such blasting, to be effective, should occur frequently, in which case the process becomes highly expensive. Before undertaking this measure, it certainly is advisable to make a thorough examination of the extent of the hardpan, its nature and depth and the type of soil underlying the layer. If underlaid by a heavy substratum like clay, blasting is inadvisable. The extent will not so much be that of opening the soil by cracks and crevices, but rather that of forming a watertight compartment, the clay being compacted all round by the force of the explosion.

The effect of the texture of the subsoil on the use of water is quite material. A heavy soil strata occurring at depths of three to six feet is of much aid both in retaining moisture and in the cross percolation of furrows. The heavy subsoils are in general not entirely impervious to water, the irrigation water penetrating them but the rate at which such water escapes by deep percolation is materially reduced so that the moisture is held for longer periods within reach of

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the plant roots. Such a condition is more favourable than an impervious layer like hardpan as in the latter case great care is required to prevent water-logging of the soil.

Where there is no heavy subsoil to assist in causing lateral percolation, the ease with which moisture can pass downward lessens the extent of lateral percolation and a closer spacing of furrows is required to secure an even distribution. A large part of the water applied may also under these circumstances be lost by deep percolation in the upper part of the furrow before the water has reached and irrigated the lower portion.

When the soil is underlaid with gravel, or if gravel seams pass through it within ten feet of the surface, the normal distribution of the soil moisture is disturbed. If gravel is mixed uniformly with the soil from the surface downward, or at varying depths, the soil may be looked upon as being continuous so far as the distribution of water is concerned.

When water, moving downward, reaches a layer of loose gravel, the descent of the moisture film is first arrested, then the film is thickened until the lower soil pores are filled and, if irrigation is continued, gravitational water drips from the soil into the gravel below. The water which thus passes into the gravel cannot move back by capillary means and usually the plant roots. Such a condition is more favourable than an impervious layer like hardpan as in the latter case great care is required to prevent water-logging of the soil.

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Soils, in which such gravel seams occur, should therefore be irrigated lightly. Not enough water should be added to allow any part to move into the subsoil. Under such conditions more frequent applications of water become necessary.

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In irrigation it is the object to reduce the surface run-off, evaporation and percolation losses as far as practicable, thereby keeping a maximum amount of the water applied stored in the soil within reach of the roots until such time as it is needed by the plant.

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The movement of water, as already explained, is from the thicker to the thinner water film or from the wetter to the drier parts of the soil. When therefore the immediate top layers of the soil lose their moisture by evaporation, there is a tendency to partly realace this loss by an upward movement of water from soil particle to soil particle from the watter subsoil. drains away into the subsoil and is lost to the plant. Solls, in which such gravel seams occur, should

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#### CHAPTER VI

EVAPORATION, PERCOLATION AND SURFACE WASTE LOSSES

The water applied either by precipitation or by irrigation to the land is disposed of in two ways: part of it runs off and is wasted, and part of it soaks into the ground. This latter part is disposed of in three ways (1) by plant transpiration (2) by evaporation and (3) by percolation.

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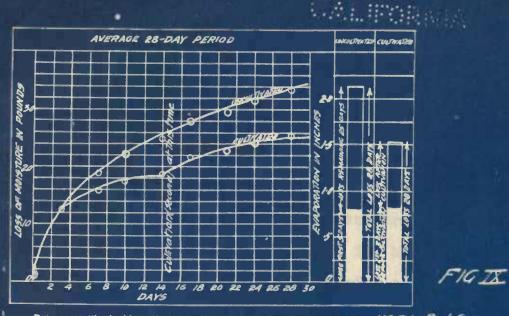
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In soils a similar condition is met, when part of the moisture is extracted, there is a thinner moisture film condition throughout the entire mass. But the degree of drying out is not uniform throughout the soil. It is only in the topmost layers that the process may extend to such a degree that the moisture film is reduced to a minimum for capillary movement. As the *ldefile*-capillary point is approached, the upward movement becomes more and more sluggish, and it is very difficult to reduce the lower soil layers below this point even though the upper layers may have a considerably decreased moisture content. To stop this upward movement and thereby the surface evaporation is a chief consideration in irrigation farming where water economy is a vital factor.

The nature of the soil is of considerable importance. The finer the texture of the soil the more rapidly will be the upward movement of the moisture to be changed As evaporation proceeds from the top soil, the water in every soil layer diminishes to the full depth of the root zone. Dr. Widtsoe likens the action to that of cotton packed loosely in a box. By removing a small quantity, the remainder expands occupying the asme volume as before, but in a looser condition.

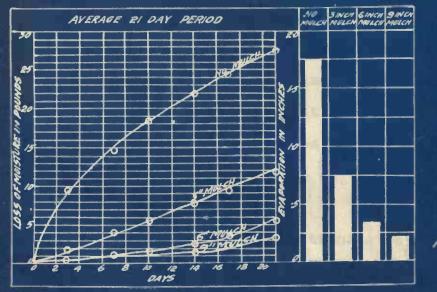
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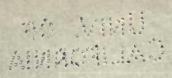
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Dragram illustrating the saving obtained by cultivation USDA Bul E



FIGX

Diagram showing the effect of mulches of various depth on the amount of water evaporated. U.S.D.A. Bul. 2



into vapour. The darker the colour, the more heat it absorbs and hence the greater the evaporation. The richer the soil is in soluble salts, the slower is the evaporation of water into the air.

Of the meteorological factors, the evaporation is most largely influenced by the temperature, sunshine, relative humidity, wind and rainfall. The higher the temperature, the more rapid is the conversion of water into water vapor. Much more water is lost from a wet soil on a sunny day than on a cloudy day. The drier the air, the more rapidly will the air take up water vapour. Winds, likewise, exert a strong drying effect on soils, especially in the case of relatively dry wind. It has also been shown that the wetter the soil is at the surface the more rapidly will be the water evaporated therefrom. The evaporation of water from a soil varies as the initial percentage of the soil moisture.

The results of the observations at six stations at which evaporation experiments were conducted under Dr. Fortier are shown in Tables XVI and XVII. The saving by cultivation is also clearly shown in Figure IX. into vapour. The darker the colour, the more heat it absorbs and hence the greater the evaporation. The richer the soil is in soluble salts, the slower is the evaporation of water into the air.

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Total 28 da Equiv	Aver- age	7	6	G	\$	63	N	F			T.T.OC	Pe-
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	147.0 143.8	42.4	43.8	42.7	151.6	41.7	138.8	40.4	l cent	per-	mid-	Mean
	1 7.9	8.2 8	1 9.0	00 53	1 7.9	9.3	1 8.0	00 • 5	'hour 'miles	wind	of.	
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133.81	1.73	2.17	1.87	3.19	2.25	3.58	5.79	13.23	Loss	5 and 6	Tanks	
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TABLE XVI

TABLE XVII/9)

Table showing the losses from free water surface and from cultivated and

uncultivated tanks at various stations

The average total losses shown by the above data are 2.13 inches from	Average 1 1 66.2 1 .35 10.35 8.41 1.58 2.14 2	Bozeman, Mont.   1   64.4   .99  17.80   4.38   2.30   2.92   2	Agricultural 2 74.5 .57 11.13 1.37 1.59 1	Caldwell, Ida.   2   72.2   .14   6.21   9.81   1.91   2.42   2	Reno, Nev. 2 56.6 .39 8.88 8.49 1.09 1.51 2	Davis, Calif.   2   64.5   .00  12.85   9.41   1.36   1.91   2	Sunnyside, Wash. 1   65.2   1.00   6.00   7.25   1.47   2.47   4	Stations Wo. of Temper- Total Free Evapora- Loss Loss trials ature rain- water tion from from culti- cent fall in free wa- vated tivated per- ter sur- soils soils soils soils soils inches inches inches inches
	2.14	2.92	1.59	2.42	1.51	1.91	2.47	es ed ct ed
from the un-	26.4	21.2	12.8	21.0	27.8	28.2	40.3	Saved by cultiva- tion percent

cultivated and 1.58 from the cultivated soils, being 35.5 and 26.3 percent re-spectively of the total six used in irrigation. The reduction by cultivation amounts therefore to 25.8 percent.

TABLE XVIIA

Table showing the losses Trom IPSE Water surface and from cultivated and

and the second	aroîtata	Sunnyaide.Wash.	Davis, Calif.	Reno, Nev.	Caldwell, Ida.	College.N. Mex.	Boseman, Nont.	Average
5	To oll brials	Lang	03-	03	03 .		-	
uncultlyated	Tamper- sture per-	S.33	64.5	9.38	5.ST	74.5	Q4* 4	S. 33
ted tanks	Tein- Tein- Inches	J. 00	00.	98.		73.	66.	38.
98	LTR Per- Per- Per- Pree	00.0	178.85	88.8	16.81	1	,TA.80	170°22
Various s	Luspors- trom trom ter sur- face ter sur-	C125-7	9.41	8.49	0.0J	JT.IS	4.28	8.4J
anoltata	Loss Loss Vated Solls Solls	J. 47	1 J. SG	60.L	T.91	7.8.T	08.5	1.58
	Loss from from from from from from from from	74.S	T. 91	I.51	S. 45	ч. 80 0	se.s	1 8.14
	Saved by thon percent	40.3	2.82	8.73	ST.O	12.8	s.rs	· A. 88 1

The average total losses shown by the above data are cultivated and 1.58 from the cultivated soils. being spectively of the total six used in irrigation. The amounts therefore to 25.8 percent. 2.15 inches from the un-55.5 and 26.5 percent re-reduction by cultivetion

T.M.

The process is not difficult to understand. Water moving toward the soil surface must pass from particle to particle through the various films at the points of contact of the soil particles. The smaller or the fewer these points of contact, the more difficult will be the upward movement of the water. When the top soil is loosened, the points of contact between the loose soil above and the compacted soil below become reduced, and hence the ascending water finds it difficult to pass through the fewer points of contact. The more thorough the cultivation, or the fewer the points of contact, the more difficult will be the upward movement and the greater will be the reduction in evaporation losses. It therefore follows that the deeper the mulch, a greater saving can be expected. That this is the case is shown by Table XVIII which shows the average losses by evaporation from a free water surface and from tanks with mulches of different depths at five different surface for a period of the stations. age loss was 27.4 pounde, abica is equivalent to 1.75 indies

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Period	Days	Loss from	No Mulch	Loss from 3" Mulch	Soil 5" Mulch	Mulch
	1	Inches	Pounds	Pounds	Pounds	' Pounds
First	13	.86	1 9.6	1.9	.48	.48
Second	1 4	.95	5.1	2.1	.56	.56
Third	1 3	.87	1 3.7	1.6	.63	.25
Fourth	1 4	.95	1 3.6	2.3	.89	.43
Fifth	3	.97	1 2.3	1.5	1.08	.53
Sixth	1 4	.99	1 3.1	2.4	1.73	1.07
Total	'21 '	5.59	27.4	11.8	5.37	3.32
Equiva- lent loss in inches	1 40 1 1		1.75	.75	.34	1 1 1 22

TABLE XVIII(9)

Fable XVIII and Figure X show that from an open unmulched soil surface for a period of three weeks the average loss was 27.4 pounds, which is equivalent to 1.75 inches of water. The percentage saved from each depth is shown in Table XIX.

that it is gained without the shider with specificate a set

	Contraction of the second					
	1 <u>8011</u>	nors stron	OM	Loss from	Days	Period
Mulch	Mulch				I	
Pounds	Pounda	Pounda	Founds	Inches	1	
84.	8≱.	1.9	0.0	88.	5	First
. 56	. 56	8.1	5.1	.96.	4	Second
.25	.63	1.6	3.7	. 87	5	Third
.45	08.	2.3	5.6	.95		Fourth
.53	1.08	1.5	8.8	. 70.	5	Fifth
1.07	24.T	2.4	3.1 <sup>1</sup>	90.	4	Sixth
5.32	5.37	11.8	27.4	5.59	21	Total
	f.		I .	1	1	Equiva-
88.	. 34 ·	.75	1.75	i i	1	loss in inches

TABLE XVIII/9)

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TABLE XIX (9)

Condition of Sod		Percent of wa-	Percent of saving on evaporation from unmulched soil
No mulch	1.75	29.2	1 00
3" mulch	.75	12.5	57.0
6" mulch	.34	5.7	81.0
9" mulch	.22	3.65	87.5

The saving therefore of a six inch mulch and a nine inch mulch varies but little and it is questionable whether it is economical to go beyond the six inch depth.

In localities where the available water supply is limited and where the duty of water is high, conditions have forced the irrigator to resort to methods of irrigation which will result in a lesser waste of water than that of flooding the entire surface. In orchard irrigation expecially, but also very extensively in all crops that are grown in rows, furrow irrigation has been largely adapted. The present tendency is to use deeper furrows than formerly used. The reason of this practice is not far to seek, in that it is quite evident that under such conditions a smaller percentage of moisture will rise by capillarity to the surface to be evaporated.

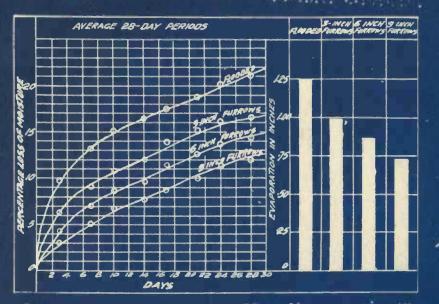
				and the second s
Fercent of saving on evaporation from unmulched soil	ation loss Percent of wa- ter applied		n of Sod	Conditio
00	29.2	1.75	in the literature of the liter	No mulch
57.00	12.5	.75	1	5" mulch
0.18	5.7	1 A&.	1	6" mulch
87.5	3.65	1 88.	1	9" mulch

TABLE XIX (9)

27

The saving therefore of a six inch mulch and a nine inch mulch varies but little and it is questionable whether it is economical to go beyond the six inch depth.

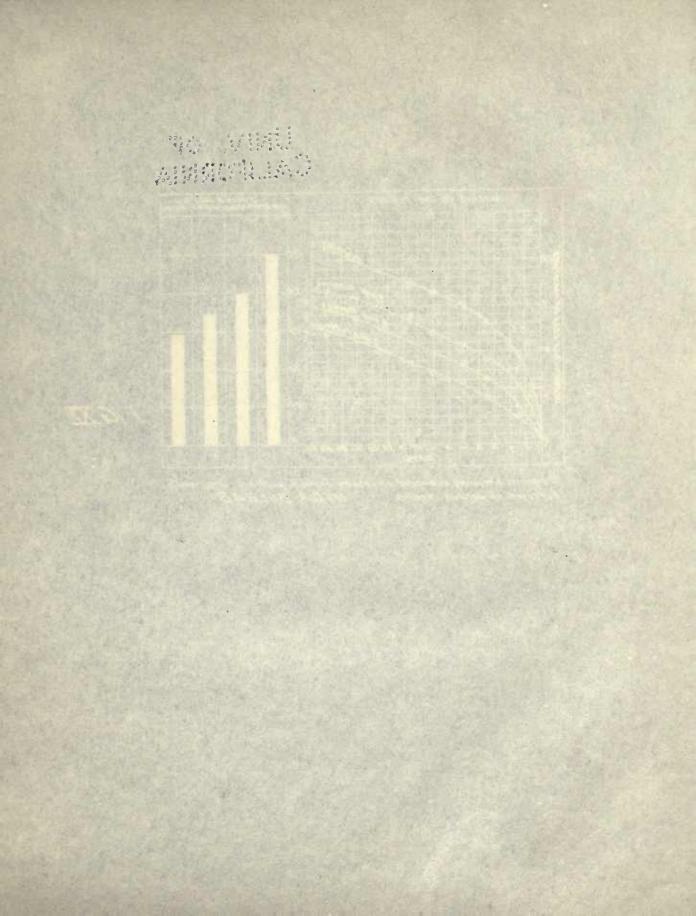
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FIGX

Diagram showing evaporation losses from Flooding and with Furrows of various depiles. USDA. Bul. 248



Tables XX and XXI give the result of the experiments conducted by Dr. Fortier to determine the saving of water by various depths of furrows. The tanks received a six inch depth of irrigation water, followed by a six inch mulch as soon as the soil could receive it. The results are illustrated in Figure XI.

										E F	
	19-65	GN	1.32	1.12	1.10	1.15	1.83	5.17	9.14	Loss	
D R	121.0	6.	1.4	1.2	1.0	1.2	0.3	5.4	9.7	Per-	120
	39:91	· 40	. 90	5-4 1-3 1-3 1-3 1-3	1.80	1.15	1.58	2.37	5.95		S" TY
	126.6	én	1.0	1- 01	9.1.9	1.10	1.7	10.7	0.0	Ferr	TTOWN
	13.44	.68	6	1.15	in the	1.00		2.50	4.00	Loss	
	¥ 14.4	4 . 7	1.1.1	1.2	1.0	* 1.1	H- CA	1 2.7	4.5	Per-	
	111.30	.70	1.22		1.12	.85	1.68	1.85	2.85	Loas	1 a.b.
	0.21	.7		1.13	1.2	.0	1.7	1 2.0	3.0	Per-	SEC.L.

75

Tables XX and XXI give the result of the experiments conducted by Dr. Fortier to determine the saving of water by various depths of furrows. The tanks received a six inch depth of irrigation water, followed by a six inch mulch as soon as the soil could receive it. The results are illustrated in Figure XI. Water surfac

Total Loss Equivalent Period 00 2 5 CT CN 2 1 28 Days 4 CN CN 4 CN 4 CN 1 loss Water <sup>1</sup>face <sup>1</sup>inches "Loss f in 10.46 1.10 inches .47 . 20 . 50 .60 from 40 07 12 sur-19.65 21.0 1.12 3.17 9.14 1.83 Loss Per-1.32 1.10 Flooding . 15 82 .25 -'cent 3.4 9.7 1.2 1.2 2 .0 .4 .0 N 15.62 16.6 N Loss -C CA --.45 .90 .22 . 80 = • .95 58 15 57 furrows 86 Per-2.7 1.9 0 F +. -.7 · ST .0 -2 N -13.44 6= 2.50 4.00 Loss 1.15 1.00 1.68 -1.43 .68 00 furrows .86 -14.4 cent Per-2.7 4.3 1.5 2 1.8 +. ŀ N H H 11.30 12.0 -1.08 1.85 2.85 Loss 9= 1.12 1.22 1.63 . 70 85 furrows 72 cent 1. 1.2 1.7 20 3.0 Per-F CN N 0 0 2

TABLE XX (9)

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Period		Ч	¢.5	ŝ	4	N	Ø	4	0	Total	Bdul vel
1 Deva		10	4		4	83		ю Ю	41	82	Equivelent loss
1. 100	Water sur- face finches	- J.JO	1 J.50	J. 30	J.60	J. 18	Ţ.4Ÿ	7.0Y	丁.40	10.45	asdoni ni
BILDOOLIE	Toss Per	8.14 8.	2.171 5.	T.851 2.	1 J. T.P. J. J.	J. J. J. J.	J'TSIT.	J. 1.52 J. 1.		10'02,ST'	1 7.25
2 2 TUPTOW	P Poga	0 130.3 1	4 5.57 S	0 7.58 7	S J.JE J	8 J.80 J	5   T.SS   J	4, .90, T	0, .45	SI'O TE'ES Je'	38.
	- Tos	· 2 4.00	03.S 1 7.50	84.L V.	···S   J·00	9.T . 6.	L. L . 8.	··0 [ J·00	80. 3.		
BWOTTUT	-rref a	0 4	N.S. 10	2 J.D	0	8. J.8.	ю Ч с	0 7.7		4 J4 4 JI 20 JS 0	1 38.
a" tur	Foss	03 00 10	.1.85	30.L	38 <b>.</b>	T'TS	J. 08'	T.SS	107.	IT. 50 '1	ST.
E WOTTUL	Per- Per-	0.8	0.0	J*3	0	S.L	7.S	Z.5	4.	5.0	03

ty to fift	by evapo- ration	free water surface		ed over flooded surface		'surface ir- 'rigated 'with '3" furrows		'saved 'over 'surface 'irrigat- 'ed '6"furrows	
previously	Inches	Inches	Per-			Inches	Per-		'Per-
Water surface	10.46	laar peo	1 1 1 1	ar ina	, , ,		1 1 1 1	1 1 1	1 1 1
Flooding 3 Inch	1 1.25	9.21	188.0	¦	!	1	!	F	1
furrows 6 Inch	.98	9.48	90.6	.27	21.6	1	1	1	!
furrows 9 Inch	.86	9.60	<b>'91,8</b>	.39	31.2	.12	12.2	t 1	1
furrows	1.72	9.74	'93.0	.53	42.4	.26	26.5	.14	16.3

TABLE XXI (9)

## TABLE XXI (9)

and the second									25-11-11-
1 1 1	by evapo- ration	1061/106   	rete e	ed over flooded surface	5 ed 6	ed over surface rigabed with 5" furn	ri ir- i swor	asved over surfac egirti egi	e -t
	Inches	Inches	Per-	Inches	Per-	Inches	Per-	Lucioal	-709'
Water surface	10.46								
Flooding   S Inch	1.25	9.21	0.88				 		
furrovs' 6 Inch '		9.48	8.00	72.	21.6		1 1		1
furrows' 9 Inch		9.60	91.8	.39	31.2	.12	12.2		!
'aworru'	1 27.	9.74	93.01	. 53	42.4	1 0S.	26.5	.14	116.3

77

<u>Percolation</u>. Of all the losses in the application of water to the land, deep percolation generally accounts for the greatest portion. As stated before the probable loss by deep percolation is generally from twenty to fifty percent of the water applied.

As shown by Table XIV diagrams of the moisture determinations on the alfalfa experiments at Davis farm, given previously, for the various irrigations fifty-seven, seventyfour, and fifty-four percent of the water applied percolated below the first six feet with an average of 68.8 percent.

Table XXII has been compiled for the various soils on which the alfalfa experiments were conducted, showing the loss by deep percolation.

As was to be expected the results show that the percolation losses were rether beavier on the lighter silb losm soils than on the slay soils. Fercolation may be looked upon as capillary movement of water aided by gravity, and since any capillary novement is dependent on the texture of the seil, soltes is the rets of percolation to a large extent proportionate to the texture of the soil. Reseurements have been made which show an absorption on blow sand soils <u>Percolation</u>. Of all the losses in the application of water to the land, deep percolation generally accounts for the greatest portion. As stated , before the probable loss by deep percolation is generally from twenty to fifty percent of the water applied.

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78

## TABLE XXII

				1	
Class of Soil	Average depth ap- plied per irrigation	six feet	of water retained including probable evapora-	age re- tained including	Loss due to deep perco- lation be- low six foot limit Percent
Silt loam with sandy loam sub- soil	15.02	1 1 1 1 1 5.52	1 1 1 1 6.60	1 1 1 1 43.9	1 1 1 1 56.1
	1	1	1	1	
Silt loam	12.81	4.24	5.32	41.5	58.5
Clay loam	8.78	3.50	4.56	52.0	48.0
Clay	4.72	2.20	<sup>1</sup> 3.28	69.4	30.6
Very heavy Clay	1 1 3.67	1 1.06	2.14	1 1 58.3	1 1 41.7

As was to be expected the results show that the percolation losses were rather heavier on the lighter silt loam soils than on the clay soils. Percolation may be looked upon as capillary movement of water aided by gravity, and since any capillary movement is dependent on the texture of the soil, so too is the rate of percolation to a large extent proportionate to the texture of the soil. Measurements have been made which show an absorption on blow sand soils

our be resulted; with heavy soils the difficulty is to as-

TABLE XXII

Loss due to deep perco- lation be- low six foot limit Percent	age re- tained including	of water retsined including probable evapora- tion	benlater by upper test xia of sod	Average depth ap- plied per irrigation	Class of Soil
	losses				1
			1		Silt loam with sandy loam sub-
56.1	43.9	6,60	5.52	15.02	fioa
59.5	41.5	5.32	4.84	12.81	Silt loam
48.0	52.0	4.56	5.50	8.78	Clay loam
30.6	69.4	5.28	2.20	4.72	Clay
41.7	58.3	2.14	1.06	3.67	Very beavy Clay

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Medium heavy soils	3 1	foot
Clay loams	2	feet
Loam	3	Ħ
Sandy soils	5	It

With light soils it is difficult to cover the surface sufficiently quickly so that no part will absorb more than can be retained; with heavy soils the difficulty is to secure full absorption of the water to the required depth.

It follows therefore that where for instance for alfalfa on a sandy loam the best practice would require four to seven and one-half inches irrigations (assuming a maximum beneficial seasonal use of thirty inches), it would be best to apply eight to three and three-fourths irrigations in the case of sandy soil and clay soils, -- in the first case to prevent deep percolation loss, in the second

80

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toot	soils 1	an heavy	Medic
feet	8	loams	Glay
н	3		meol
н	5	afica t	Sandj

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Depth of water received from initial absorption uniform over whole 111 check.  $\Delta B$ Depth of absorption during time water C absorption while water stands on the check. is turned into the check of absorption after Flow into check 15 shut of from 6 H Unifo it recedes down the check onded water 25 2 Diagram illustrating the method of absorption of water on sloping checks (Handing) FIG.XTT E B 4 -1 Ċ, C 4 H D. 6 Amount OF Water

Diagram illustrating the saving in water obtained by using a smaller length of check. Amount saved = shaded area HH\_D\_D\_HD.

2

FIG XIII

to secure full absorption. The most common method of applying the water to the land is by spreading it over a slightly sloping surface. Under such conditions the distribution of the water should theoretically, be somewhat as shown in Figure XII.

The depth of initial absorption efba represents the minimum depth of irrigation with which the land can be covered under any conditions. As the water travels over the check, the depth of absorption from the flowing stream will be proportional to the time during which each part of ons 337 foet the check is covered, being greatest at the upper end, as MAGES WEB CUrvied into the shown by fgb--gb being somewhat concave upward as the water will travel more rapidly at the upper end. When the water has reached the lower end or often somewhat before it has reached the end, the supply is shut off. For a short period all of the area would be covered and absorption takes place uniformly over the whole check, as shown by cheb. Gradually however the upper end will become unwatered and the water on the check will recede toward the lower end, the absorption being greatest at the lower end where the water remains the longest as represented by hdc. The total depth at the top of the check will hence be eh and will necessarily be a function of the length of the check or ea. If therefore it should octo secure full absorption. The most common method of epplying the water to the land is by spreading it over a alightly sloping surface. Under such conditions the disbribution of the mater should theoretically, be somewhat as shown in Figure AII.

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Don. H. Bark has conducted extended experiments illustrating these relations.

An experiment was conducted on a strip of clover 45.9 feet wide and 2359 feet long. The strip was divided into seven equal divisions 337 feet long and a head of approximately three cusecs was turned into the upper end of the strip. The head was held constant and the length of time that was required for the water to advance across each successive division as the stream advanced down the border check was noted. The results in Table XXIII were obtained.

would have been only saven times as long as that required by his first staip, or only seven hours and forty-nine similar, as compared to the flitteen hours and forty ainates that more required. Also an average mouth of application of only .V55 feet would have been required as applied the 1.47 feet which were required when it was florder the cur that at the head of the check water is lost by deep percolation, this can be considerably diminished by dividing the check into a number of subsections, obtaining a distribution as on Figure XIII. The dotted lines shows the distribution with an undivided check. The saving in water is therefore represented by the area HHw Dw Dr Hr D.

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An experiment was conducted on a strip of clover 45.9 feet wide and 2559 feet long. The strip was divided into seven equal divisions 337 feet long and a head of approximately three cusees was turned into the upper and of the strip. The head was held constant and the length of time that was required for the water to advance across each successive division as the stream advanced down the border check was noted. The results in Table XXIII were obtained.

Division number	of run		Time Hours		feet	Average depth in feet
1	' 337	.38	1 1	1 7	.28	.73
12	674	.77	1 2	1 30	.63	.82
13	1011	1.15	4	1 00	1.01	.88
14	1348	1.53	1 5	40	1.43	.93
15	1685	1 1.92	8	25	2.12	1 1.11
16	2022	2.30	1 11	¦ 30	2.90	1.26
17	2359	1 2.68	1 15 1	i 40	3.95	1.47

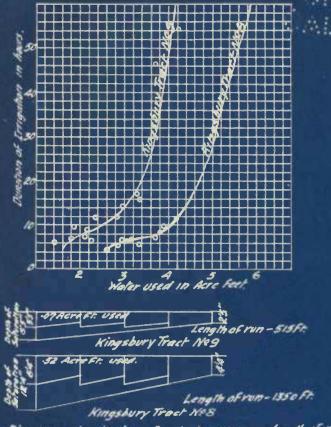
TABLE XXIII (6)

The Table shows clearly that the amount of water that is required for the irrigation of gravelly soils increases greatly with the distance over which the water is flooded. Had this strip been divided into seven sections by the construction of six cross ditches, the time required would have been only seven times as long as that required by the first strip, or only seven hours and forty-nine minutes, as compared to the fifteen hours and forty minutes that were required. Also an average depth of application of only .733 feet would have been required as against the 1.47 feet which were required when it was flooded the

Average depth in feet	feet		S 10 12		Length of run feet	Jeamn
.73	88.	4	l.	53.	337	I. I.
\$8.	63.	30	8	Fr.	674	12
88.	1.01	00	4	1.15	1011	15
.93	1.43	40	5	1.53	1548	14
1.11	2.12	25	8	1.92	1685	15
1.26	2.90	30	11	2.30	8088	16
1.47	3.95	40	15	89.8	2359	1 7°L

TABLE XXIII(6)

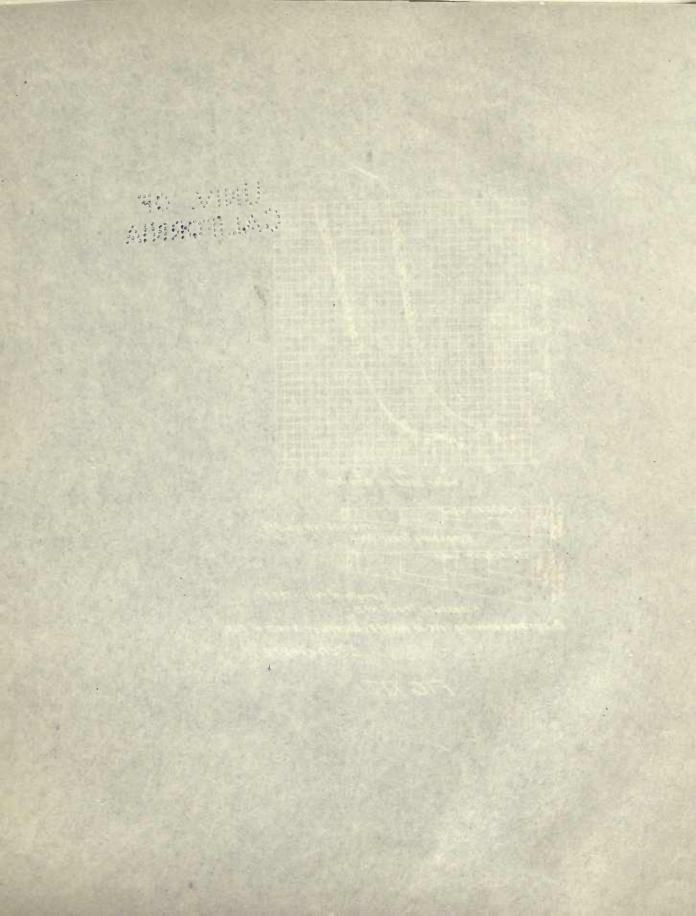
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Diagrams showing less of waterby excessive length of run.

Ercheverry

FIGXIX



entire length of the 2359 foot border. A total saving of fifty percent in the time water used would have resulted. The results emphasize the fact that the economical irrigation of especially porous soils can only be effected by flooding comparatively short distances at a time.

TABLE XXIV.61

84

The effect of varying the size of head was investigated by the United States Reclamation Service in 1910 and 1911. The curves in Figure XIV show the relation between the number of acre feet on the tract and the duration of the irrigation, which depends on the head of water used.

Table XXIV has been compiled for Kingsbury Tract No. 8, assuming various times in which the irrigation was to take place.

greater loss by deep percolation.

The degree to which these principles have been adopted in practice is shown to some extent by the following. Usually checks wary from three hundred thirty to thirteen hundred twenty feet in length, six hundred sixty being typical for medium soils. The width of the check is adjusted to the soil, slope and size of irrigating head. The ridths wary from thirty to one hundred feet for different slopes ind sizes of head, the arrower checks heing entire length of the 2359 foot border. A total saving of fifty percent in the time water used would have resulted. The results emphasize the fact that the economical irrigation of especially porous soils can only be effected by flooding comparatively short distances at a time.

18

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Table XXIV has been compiled for Mingabury Tract No. 8, assuming various times in which the irrigation was to take place.

TABLE	XXIV <i>(</i> 6)	
-------	------------------	--

'Time '	Acre feet of Water registered	Corresponding head in cusecs
1 5	2.60	6.25
1 8	3.70	5.60
10	4.0	4.8
; 16	4.5	3.02
1 20	4.7	2.85
¦ 60	5.9	1.17

The results show that decreasing the size of irrigation head, causes a proportionately larger increase in the time necessary to obtain a complete irrigation, and therefore requires a greater depth of irrigation water per acre and a greater loss by deep percolation.

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		- mainting "
Corresponding head in cusecs	Acre feet of water registered	Time !
6.25	2.60	, 5·
5.60	5.70	8 1
	0.0	1 10
5.02	4.5	, 16
28.85	4.7	20
1 1.17	5.9	

TABLE XXIV(G)

The results show that decreasing the size of irrigation head; causes a proportionately larger increase in the time necessary to obtain a complete irrigation, and therefore requires a greater depth of irrigation water per acre and a greater loss by deep percolation.

The degree to which these principles have been adopted in practice is shown to some extent by the following. Usually checks vary from three hundred thirty to thirteen hundred twenty feet in length, six hundred sixty being typical for medium soils. The width of the check is adjusted to the soil, slope and size of irrigating head. The widths vary from thirty to one hundred feet for different slopes and sizes of head, the check being used on steeper slopes with smaller head. Checks 66 x 660 contain one acre and are typical of the practice under conditions suited to border irrigation. The size of the stream varies from about .02 to .15 cusec per foot width of check or from two to ten cusecs, -- the most usual conditions being .08 to .10 cusec per foot width of check. The slopes to which this method is best adapted varies from two inches to one foot per hundred feet, slopes of four to six inches being the most usual.

In furrow irrigation it is difficult to obtain a uniform application throughout the length of the furrow. The best method to obtain a fairly uniform distribution is to either reduce the total length of the furrow, or to increase the length of the furrows in the lower portions of the fields by zigzagging them in orchards or building small basins for ponding purposes. The size of the furrows can be adjusted to the slope and head in each furrow, in light soils using as large furrows and heads as will not cause erosion; on heavy soils, smaller and longer furrows with corresponding longer "sets" should be used.

The lateral percolation in furrows has been extensively studied by Dr. Loughridge. The water applied moves not only vertically downward, but in every direction from the used on steeper slopes with smaller head. Checks 66 x 660 contain one scre and are typical of the practice under conditions suited to border irrigation. The size of the stream varies from about .02 to .15 cusec per foot width of check or from two to ten cusecs.--the most usual conditions being .08 to .10 cusec per foot width of check. The slopes to which this method is best adapted varies from two inches to one foot per hundred feet, slopes of four to six thomes being the most usual.

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The lateral percolation in furrows has been extensively studied by Dr. Loughridge. The water applied moves not only vertically downward, but in every direction from the wetted furrow. The downward movement, aided by gravity, will be the most rapid, diminishing as it becomes more and more horizontal. This is very clearly brought out by the experiments of Dr. Loughridge and McLaughlin, quoted previously.

## TABLE XXV(25)

Water removed from tanks by days expressed in percentages of amount in thirty days.

Days	Decomposed light san- dy soil 20		Heavy clay loam	Sand and gravel wash 70	Heavy lava ash 90
ı	17	22	26	1 18	1 17
3	30	36	42	30	1 29
5	38	42	51	1 36	1 37
10		58	1 67	1 52 1	<sup>1</sup> 53
15	67	70	1 78	' 64	67
20	1 81 1	81	1 86	1 79 1	' 81
30	1 100	100	1 100	100	; 100

Table XXV shows the great use of water during the first days of the experiment. In all cases more than onehalf the total quantity of water used in thirty days was used in the first ten days or one-third of the time. The wetted furrow. The downward movement, sided by gravity, will be the most rapid, diminishing as it becomes more and more horizontal. This is very clearly brought out by the experiments of Dr. Loughridge and McLaughlin, quoted previously.

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17	18	26	88	17	1 _ 1
88	50	42	<b>3</b> 6	50	8
37	36	51 /	4.C	38	5
53	52 '	67	58	53 1	10
67	64	87	70	1 70	15
18	1 67	86	81	81	20 1
100	100 1	100 1	100	100	30

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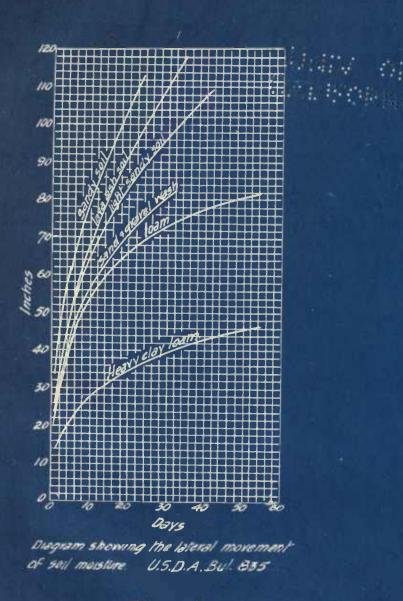


FIG XY

lighter the soil the smaller the relative percentage of water used during the first days, and the heavier the soil the greater the relative use of water during the first few days.

Figure XV from the experiments of McLaughlin shows that the heavier the soil the less extended will be the wetted area with the lapse of time. Therefore, a light soil will "sub" much farther in a horizontal direction than a heavy soil.

The law of lateral distribution of the moisture is in general of the same nature as for downward movement i. e. the water will tend to distribute itself inversely with the distance of the soil particle from the source of supply.

Observations on medium heavy apile is in the second side project indicate that by six days after moistape will be relatively unified second days after as wide as six feet where weight second and a second twenty-four hours. It use side formal second and a moisture distribution was second and a second second after irrigation with teach the second second second second spacings. With weaks set lighter the soil the smaller the relative percentage of water used during the first days, and the heavier the soil the greater the relative use of water during the first few days.

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# TABLE XXVI/25)

Distribution of moisture in horizontal flumes

Light : soil	sandy	LC 1	am	'Heavy 'loam	clay	Heavy	lava ash
Dis- tance Inches	percent	Dis- trict	Average		Average	Dis- trict	Average
3	24.38	t 9	22.85	1 3	44.58	5	31.07
9	1 20.85	22	23.10	1 12	43.61	1 9	28.85
21	20.81	34	21.25	1 34	40.49	18	27.21
45	18.22	1 52	19.50	1 30	<sup>1</sup> 39.43	1 30	26.40
69	1 16.70	64	15.85	1 33	36.33	1 42	25.57
81	1 14.24	re lou	c throug	t b even	aret;ion	54	25.47
93	! 14.18	1 1	distri	t tutes	t the sate	1 72	20.49
105	12.36	i treoduc	en a gre	t ater a	i.demag n	1 84	22.57
111	1 10.54	nda de	deeper	T Poot	t Egystem S	1 96	19.20
117	7.56	1 1_0 02 :	coud or	1	t 1914 - Cugenu	i into	t equir fur-

Observations on medium heavy soils in the Sunnyside project indicate that by six days after irrigation the moisture will be relatively uniform across furrow spacings as wide as six feet where water had run in the furrows for twenty-four hours. It was also found that fairly uniform moisture distribution was secured within forty-eight hours after irrigation with twelve hour sets on four feet furrow spacings. With sandy soils without heavy subsoils where the

							t deles h T
lava ash	Heavy	clay	Heavy	man	21	- Vouse	Light : soil
Average	Dis- trict	Average	Dis- trict	Average	Dis- trict	of the first of the second second	Dis- tance Inches
				F 1	1	- 5 1.55 G LOIN	and an extension of the second se
51.07	5	44.58	5.	28.85	6	24.58	3
28.85	6	45.61	12	85.10	22 1	20.85	6
27.21	18	40.49	.54	21.25	34 1	20.81	21
26.40	30	39.43	30	19.50	52 1	1 18.22	45
25.57	4.2	36.33	33	15.85	64 <sup>1</sup>	15.70	69
25.47	54 1	t	1	1	4 1	14.24 1	81
20.49	1 27	1	1	1	1	14.18 1	93 1
22.57	84	3	1	1	1	12.36	105 1
19.80	1 86.	1	1	1	1	10.54	111
	1	1	1	1	1	7.56	117
	1					a service and a constrained of the service of	

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furrow spacing exceeded three feet heavy downward movements occurred before the moisture met laterally between furrows with heavy subsoils at depths of from four feet. Four feet spacing of furrows gave good results. The trend of practice is in favour of a smaller number of furrows of head used per furrow. greater depth, in which small streams of water are permitted weer heads are prei to run fifty to seventy hours. This increase in the "sets" has not increased the total quantity applied in any one season for there has been a corresponding decrease in the number of irrigations. This method not only reduces the amount of moisture lost through evaporation by upward capillary movement, but also distributes the water in the subsoil more evenly and produces a greater sideway absorption. It also tends to produce a deeper root system in the crops.

The size of head or the flow turned into each furrow should be adjusted to the soil, slope and length of run --as pointed out previously. The best results are secured by using larger heads until the stream has worked through to near the end of the furrow and then reducing the amount in order to prevent excessive waste.

The size of the stream used in each furrow is most conveniently expressed by giving the number of furrows which would be set with a flow of one cusec. On heavy soils one

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hundred to one hundred fifty furrows per cusec are often used. On the heaviest types which absorb water slowly, two hundred furrows per cusec are not unusual and on steep slopes this may reach five hundred in extreme cases. On sandy soil the head used per furrow is generally 1/100 Where the slope is flat larger heads are preferable, 1,60. cusec being an average.

Surface Waste. This loss is largely dependent on the skill and care taken in the preparation of the land for irrigation and in the application of the water. The runoff collects in hollows or cuts channels to connect it with the larger bodies of surface water. When water is applied by the flooding method, it is relatively easy to control the run-off by building levees around the field -- as in the Border and Check methods. In such cases the waste should be negligible in amount. Flooding methods will on an average give a ten percent waste and furrow irrigation, due to the greater difficulty in obtaining a uniform distribution, will generally have a somewhat larger waste. In any case, the run-off water should be carefully and skilfully used on lower fields. The problem is one which must be solved on its merits on each individual farm. No general rules can be laid down for using the run-off, as necessarily this use

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lands do not require any artificial fertilizer because of

the fact that the water TABLE XXVII also the requirement

Average waste from fields under different crops at Billings, Montana. (Harding)/21)

tility of an plied irrig	obser- vations	'Mean 'per-		Mean per-	1	'Mean 'per-	All S No. of obser- vation	'Mean 'per-
Alfalfa	56	19	78	4.5	20	5.7	154	10
Grain	15	15	36	5.5	. 11	14.3	62	19.4
Cultivated Crop	1 1 1	20	20	• •6	1 1 6 1	9.2	1 1 39 1	1 1 <b>8.</b> 5
Mean for all	84	18.5	134	4.5	1 1 1 37	9.0	1 1 255	9.7

Rio Grande

Salt River + 26

Colorado

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## TABLE XXVII

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All Solls No. of Lean obser-'per- vations'cent- 'age 'of	Mean per-	Ligh S No. of obser- vation	Mean per-	Medium No. of obser- vations	Mean per-		
154 ! 10	1 5.7	08	4.5	78	19.	56	Alfalfa
10 · C · · · · ·	14.5	11	5.5	36	15 1	15	Grain .
39 <b>8.</b> 5	1 S.8 1	9	1 1 <b>∂</b> .	80	20	13	Cultivated Crop
265 <sup>1</sup> 9.7	1 0.0	57	1 1 1 1 1 1 1	1 1.34	18.5	1 1 1 84	Mean for 1 all 1

# CHAPTER VII

THE FERTILITY OF THE SOIL

It is often taken for granted that irrigated lands do not require any artificial fertilizer because of the fact that the water itself furnishes the required fertility. While a good irrigation system does have great advantages and while the silty waters used in irrigation frequently carry valuable fertilizing material (See Table XXVIII), dependence for maintaining and increasing the fertility of arid lands cannot be placed wholly upon the applied irrigation water.

# TABLE XXVIII

Showing the amount of fertilizing silts in various rivers of the U.S.A. (Etcheverry)

the soil its concity sifered

River		Pounds of Phos- phoric acid per acre foot of water	Pounds of Nitro- gen per acre foot of water
Rio Grande	325.5	31.4	24.4
Salt River	265,	1. 10.5	9
Colorado River	116.34444.60	2.2643.56	1.0369.7

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gen per acre	Pounds of Fhos- phoric acid per acre foot of water	ash per scre foot of water	
24.4	51.4	525.5	Rio Grande
	1 10.5	265,	Salt River
1.0369.7	2.2645.56	1 116.54 <b>444.60</b>	Colorado River

Even in Egypt, where the Nile sediment has a high fertilizing capacity, it has been found that manure and artificial fertilizers should be used. Sir William Willcocks in his "Egyptian Irrigation" says (4)

"It would be a healthy innovation, indeed, if the provision of suitable manures were to be considered as an essential part of the project for providing perennial irrigation. The day is not distant, I believe, when governments which provide irrigation works will also provide manures, and sell the water and manures together, one being as essential as the other. I know well, from observation, that a well manured field needs only half the water that a poorly manured field does; and in years of drought and scarcity manures almost take the place of irrigation. Why should there not be a manure rate as well as a water rate?"

Organic matter, especially when it has been reduced to the form of humus, has a great capillary capacity, far excelling in this regard the mineral constituents of the soil. Its porosity affords an enormous internal surface, while its colloids exert an affinity for moisture which raises its water capacity to a very high degree. Its tendency to swell on wetting is but a change in condition when approaching its maximum moisture content. The following data, taken from Lyon Fippin and Buckman, give an idea of the capillary capacity of the soil organic matter. Even in Egypt, where the Mile sediment has a high fertilizing capacity, it has been found that manure and artificial fertilizers should be used. Sir William Willcocks in his "Egyptian Irrigation" says (4)

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	Humous extract from pe	ax//6/		tage of 1200	water
Gr	Non-acid extract from Vegetable mold	peat Stor	er Tons	645 309	re.
	Peat			190	
o	Garden loam 7% humus	Manure		96 Te	Aver- age
57.	Illinois prairie soil Field loam 3.4% humus	1 1 2.11	1 3.25	57 52	3.09
Ģ1.	Mountain Valley loam 1		us	47	13.58

Even after allowance has been made for an increased hygroscopic coefficient due to an increase in organic matter, the effect of the latter is very strongly marked on the capillary capacity of a soil. It is equally evident that with a well manured soil there will as a consequence be a marked economy in the amount of water used to procure a reasonable crop.

The experiments at Utah on grain and stover gave the following results--an average of six years.

than with twenty inches of water, bit the yield was decreased with forty inches. The average of six rears shows that water applied in excess of twenty inches to corn was not only wasted but was postively injurious to the yield of grain. The yield of both grain and staver was decidedly increased by manure, the stower showing the effect considerably more than the grain

of water	Percentage 1200	Humous extract from peat
	645	Non-acid extract from peat
	309	Vegetable mold
	190	Pest
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TABLE XXIX (16)

gation ap- plied	ent on			inté ni	Stov	nd th	hoold :	(lenga
					'manure			
None	57.9	1 73.3	75.9	1 67.0	2.11	1 1 3.25	1 3.92	13.09
5	61.0	86.1	91.4	1 79.5	2.32	3.77	4.48	13.53
10	59.7	83.0	92.5	1 78.4	2.55	3.73	4.25	3.51
20	67.6	87.7	99.1	84.8	2.81	4.04	4.85	13.90
30	63.1	90.4	95.7	83.1	2.86	4.19	4.77	13.94
2	63.9	83.8	90.0	79.2	2.88	4.07	4.50	3.81

The results show the highest yield of grain with a twenty inch irrigation duty; more than this quantity of water decreased the yield, and with as much as forty inches of water there was slightly less grain than with five inches. A somewhat higher yield of stover was obtained with thirty inches than with twenty inches of water, but the yield was decreased with forty inches. The average of six years shows that water applied in excess of twenty inches to corn was not only wasted but was postively injurious to the yield of grain. The yield of both grain and stover was decidedly increased by manure, the stover showing the effect considerably more than the grain.

						1 Bushel		Irri- gation ap- plied
Aver-	15 tons manure	5 tons manure	No manure	Aver- age	15 Ions manure	5 tons manure	No manure	Inches
5.09	3.92	3.25	2.11	67.0	75.9	73.3	57.9	None
8,53	4.48	3.77	2.32	79.5	91.4	86.1	61.0	5
8.51	4.25	3.73	2.55	78.4	92.5	0.38	59.7	10
5.90	4.85	4.04	2,81	8.48	99.1	87.7	67.6	20
3.94	4. 77	4.19	2.86	83.1	95.7	90.4	63.1	30
3.81	4.50	4.07	88.8	79.2	0.08	8.88	63.9	

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TABLE XXIX/6/

The increase was much greater for each ton of manure with the five ton than with the fifteen ton application.

Most of the soils of the irrigated regions are deficient on humus and organic matter, and it should always be the first object to supply this necessary amount of fertilizer. This is usually done by the growth of alfalfa, clover, peas or some other legume, turning in the green crop and thus putting the nitrogenous matter directly into the ground. It is often desirable and necessary to supplement this by some form of fertilizer, usually the ordinary stable or barnyard manure.

If leguminous, it is generally grown as a cover crop during the non-irrigated months of the year. Much of the success of this method is dependent on the skilfull handling of the water supply. During winter months the cover crop will receive all the necessary water from the rainfall, but great care must be exercised during the summer months that the water intended for the main crops is not absorbed by the cover crop to the detriment of the first. In some localities an extra amount of water is put on the land especially for the cover crop, --being in addition to the required amount of the main crops. In other districts again, it is the practice, to apply only sufficient water for the main crops and to let the cover crops care for themselves. It is

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only by experience that one can obtain the best practice --each district having its own individual merits.

The amount of organic matter can be greatly increased by always ploughing in the stubble of the previous crop. On no account should it be burnt. By burning all the nitrogen is taken away by oxidation and only ash left. the will A thorough rotation of crops also greatly helps in retaining the amount of organic matter. Experimenting in Oregon Professor W. L. Powers states that "It is probable that the water requirement may be decreased one-third where a good crop rotation is practiced. " a necessary to take into consideration, in addition to the above, the effect of such useful part of the crop. It is hence of importance to know in what way the general growth of the plant is effected by a variable application of water.

Assimilation and other processes favouring plant growth are especially rapid after an irrigation, gradually diminishing in intensity and almost ceasing before the next irrigation.

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#### CHAPTER VIII

# THE CROP

In one of the previous chapters it was stated that under ideal conditions, irrigation should take place when the soil moisture has reached a point somewhat above the wilting coefficient, and that the frequency of application would be dependent on the time taken by the soil to "dry up" after the application of water to the next stage just above the wilting point. This applies, of course, only theoretically. In practice it is necessary to take into consideration, in addition to the above, the effect of such waterings on the crop itself, at the particular period at which the water is applied. It is not so much the case of obtaining, by irrigation, a maximum amount of dry matter per cusec of water applied, but rather a maximum yield of the useful part of the crop. It is hence of importance to know in what way the general growth of the plant is affected by a variable application of water.

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CHAPTEN VIII

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In the Utah experiments it was found that during

the first week after the irrigation of peas, more than five hundred pounds of dry matter were added to the weight, and of oats, more than seven hundred pounds of dry matter were added to the acre.

The vigour and general condition of the plant depends largely upon the development of a good, deep root system. In the early stages of growth, the plant uses most of the materials gathered from the air and soil for the development of its root system. When these are well developed, carbon assimilation by the leaves is hastened and the growth is increased rapidly. Later in the life of the plant, the root growth becomes less, and the energies of the plant are more largely directed to the development of the parts above ground. When at last the stems are well developed and a sufficient quantity of material has been stored in the various plant organs the growth diminishes, first flowers and then seeds being developed. It is important, therefore, that as early as possible the root system be made large and well developed. To obtain this condition it is essential to keep the soil moderately wet in early spring. In districts retentive where the winter rainfall is large, deep/soils will usually have sufficient water for the initial root development and no irrigation need be applied. If however the climate conditions are such that at seeding time the soil is not well

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is not well filled with water, thorough irrigation immediately before or after planting is essential to a proper root development. The part of the plant above ground is also definitely affected by the quantity of water applied. As the water applied to the soil increases, the plant becomes longer. With a lack of water the plant remains short. Not only the stalks but also the proportion of leaves is distinctly affected by the amount of irrigation water applied.

In a grain crop the value of the straw is small in comparison with that of the seed. Hence as much of the plant as possible should be converted at harvest time into seed. On the other hand when a crop is grown for forage it is desirable to secure the largest proportions of leaves. The following extracts from various reports and papers fairly establishes the practices governing these basic principles of plant growth.

> <u>Alfalfa.</u> "Where the winter and spring precipitation is sufficient, or where winter irrigation has been practiced, soils which have good soil moisture retentive power need no irrigation before seeding the first crop, which in most localities generally occurs in the spring months after the danger of killing frosts is passed. Porous soils which have little retentive power for soil moisture usually require irrigation before seeding. After seeding the young alfalfa plants should receive no further irrigation until the plants show the need for water or even not until they show signs of suffering for lack of moisture; this is desirable to develop the root system

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"The soil should contain suf-Cereals. ficient moisture at the time of seeding to germinate the seed and to start the plants growing. No irrigation before seeding is required for a retentive soil when winter precipitation is not too small, or when the soil moisture has been supplied by winter irrigation. Irrigation before seeding is necessary for a soil which is too dry because of deficient winter precipitation or irrigation. Where irrigation before seeding will keep the ground wet too long and delay the seeding, it may be necessary to irrigate immediately after planting. This practice is objectionable for soils that have a tendency to bake; it increases the evaporation loss and requires an earlier second irrigation.

After the plants have germinated, the first irrigation should not be applied until the plants require it, but before the plants begin to suffer for moisture, which for a moderately retentive soil will be two or three months after seeding when the plants shade the ground and have grown to a height of six to nine inches. A second irrigation is usually necessary when the heads just begin to form, and a third irrigation is often desirable when the heads are filling out. The practice will vary especially with the character of the soil and the time and extent of precipitation; a good retendownward instead of confining it to the surface, as may occur with too early irrigation. The root system can be further strengthened by cutting the young alfalfa when eight inches high. When the root system the common practice on retantive soil is to apply one irrigation before or after cutting. On gravelly porous soils and on shallow soils, two on even three irrigations for each cutting may be necessary.

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"In a number of irrigation experiments with grain the best results were obtained both in quantity and quality of yield with three irrigations at the jointing, booting and soft dough periods. At the jointing the embryo head is forming, at the booting it is about to emerge and at the soft dough the kernel is filling. [Harding]

"At the Utah Station the growth of wheat was divided into four stages (1) when -five leaves had developed and the plants were 6"--8" high (2) the early boot stages when the plants were just swelling preparatory to heading (3) the bloom stage, when most of the plants were in bloom and (4) when the plants were in the dough stage. The experiments were conducted on a loam soil. The experiments were conducted on a loam soil. The precipitation averaged 17.8 inches and 37.3 bushels per acre were raised without irrigation. The highest yield of wheat was produced with three irrigations of five inches each applied at the five leaf, the early boot and the bloom stages. Irrigation applied after seeding before the grain was up and that applied after the dough stage, decreased the yield. Where only one irrigation was given the best time to give it was at the five leaf stage; where two irrigations were used the five leaf stage and boot stage were best; where three irrigations, the five leaf, boot and bloom stages were best. (Harding)

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seeding. Dry soil must be irrigated before planting. Planting in dry hot soil, followed immediately by irrigation is not desirable. During the first stages of growth throughout cultivation is more important than irrigation, and no irrigation may be necessary until July. Too early irrigation after planting may compact and bake the soil around the roots. Potato vines are shallow rooted and frequent irrigations, especially early in the season when the water is cold, will retard the growth; for this reason some irrigators prefer to apply the water at night, when the soil and water have had all day to warm up in the sun. The moisture in the soil should be kept fairly uniform until the tubers begin to form, when a heavier irrigation is generally required. The soil should not be allowed to harden around the roots. The last irrigation should be applied before the growth of the tuber ceases, in order to give about 12--2 months for ripening in dry earth. The number of irrigations will vary from two to four for sandy loam and from four to six light irrigations for a porous sandy soil or a shallow soil. The need of irrigation may be indicated by the appearance of the plants: dark leaves indicate a lack of moisture, light yellowish green leaves indicate an excess. An examination of the soil where the tubers form is another good indication. A sandy soil is in good condition when a ball of earth squeezed in the hand will retain its shape. "(6)

<u>Cotton</u>. "Soils for cotton should be given sufficient moisture for germination before planting. With cultivation no further irrigation should be required for six weeks to two months. From two to four light irrigations are given during the period of plant growth. Too heavy irrigations at this time results in excessive vegetative growth at the expense of crop production. After about July 1st, the crop on most soils will re-

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Orchards. Deciduous trees are deep rooted when the soil conditions are favourable; they require less water than other irrigated crops and for that reason the need for irrigation is not so apparent. Citrus trees are not as deep rooted as deciduous trees; they are evergreen and therefore the evaporation from their leaves is continuous and the maximum moisture need for fruit growth is in the fall; for these reasons citrus trees require more irrigation than deciduous trees.

Fall and winter irrigation is very advantageous in the maintenance of orchards, where the greater part of the rainfall does not occur in these periods. As a general rule trees must not be irrigated, or very cautiously, when they are in bloom, for such early irrigation is said to interfere with the setting of the fruit.

> "Orchard soils should not be allowed to dry out too much for an excessive dryness in early or middle summer will injure the tree for the whole season. On the other hand, over-irrigation tends to decrease fruit production and delay the ripening."(6)

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The last irrigation is given in the first week of September, so that the new wood may have a chance to mature before any freezing occurs. This late irrigation also has the advantage of keeping the leaves somewhat longer on the trees, aiding thereby the formation of the new wood.

Young trees should not be irrigated more than once or twice a season. This is essential to the formation of a deep drought resisting root system. Professor Wickson draws the following conclusions:

> "For deciduous fruit trees on deep soils, fairly retentive, ten inches of irrigation water, applied at the proper time, during five months of growth and fruiting, accompanied by good cultivation, is sufficient, even when the rainfall is only about enough to prevent drying out during the winter.

> For citrus trees twenty inches of irrigation water is usually sufficient where the rainfall is considerable and for the more retentive soils, ten inches applied at the right time may be adequate."

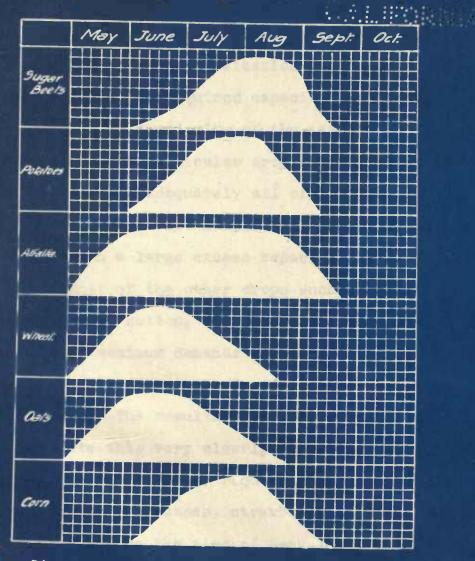
A diversification of the irrigated crops will usually result in an increased duty. The reasonable water requirement should not be based on the needs of the crop of maximum water requirement but rather on the average water requirement for the entire ares,--the average being of course proportional to the areas which each type of crop occupies. By diversifying his crops the farmer's need for water will be The last irrigation is given in the first week of September, so that the new wood may have a chance to mature before any freezing occurs. This late irrigation also has the advantage of keeping the leaves somewhat longer on the trees, siding thereby the formation of the new wood.

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Disgram showing the Seasonal use of water by various crops in Cache Valley, Utah. Utah Ag.Coll. Bul. 173

FIGXYL

more uniform and constant, instead of the greatest need for water falling within a comparatively short period. The same applies to an entire irrigation project, helping materially in the proper distribution of water by rotation. The greater the diversification of the crop the more uniform will be the required capacity of the main canal.

If a majority of the acreage of any project is planted to one particular crop, say alfalfa, it is impossible to serve adequately all of the land in that crop at the time of greatest demand, unless the canal has been designed with a large excess capacity for that particular purpose. Most of the other crops such as grains, potatoes, corn, beans, cotton, etc., have a lower water requirement and their maximum demands do not extend over as long an interval of time as that of alfalfa or are not of the same magnitude. The results from the Cache Valley experiments illustrate this very clearly. (See Figure) In fact some of the crops of low water requirement such as fall planted grains, early potatoes, strawberries, etc., may be cared for entirely before the time of peak load. Other crops of low total water requirement, but which may require water during the peak of the season, are corn, beans, sorghums, etc. Potatoes and sugar beets may require as much water as alfalfa

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In crop selection and carefully planned crop rotation may be found one of the most practical means of reducing the peak load of an irrigation system and maintaining a generally high water duty. If this peak can be distributed through the season, it will result in a lower construction cost, and in many economies in operation and maintenance.

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#### CHAPTER IX

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YIELD OF VARIOUS CROPS UNDER VARYING AMOUNTS OF IRRIGATION APPLICATIONS

Under the direction of Dr. Harris of Utah a very complete set of experiments has been conducted to determine the effect of varying quantities of water on the crop yield. The experiments were conducted in Cache Valley, Utah, and extend over a period of some fourteen to seventeen years. Whilst of course these results are strictly only of practical benefit to the area concerned, it nevertheless gives an accurate reflection of conditions under which a maximum of various crops may be obtained. The results obtained are reproduced below, together with results obtained from various other sources.

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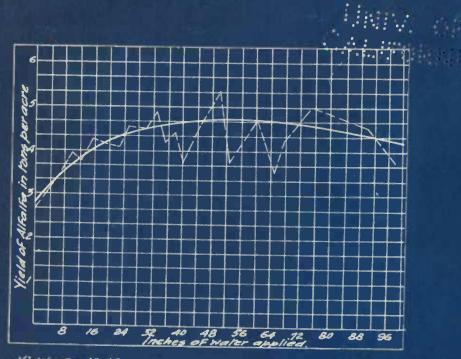
The following table shows the average of a total of one hundred seventy-six trials extending through fourteen years. er number of tests to be nearer to the true average than the average of a fewer number and weighing accordingly. A one year test is not given the same weight in arriving at a point for the heavy curve to pass through as a test covering several years.

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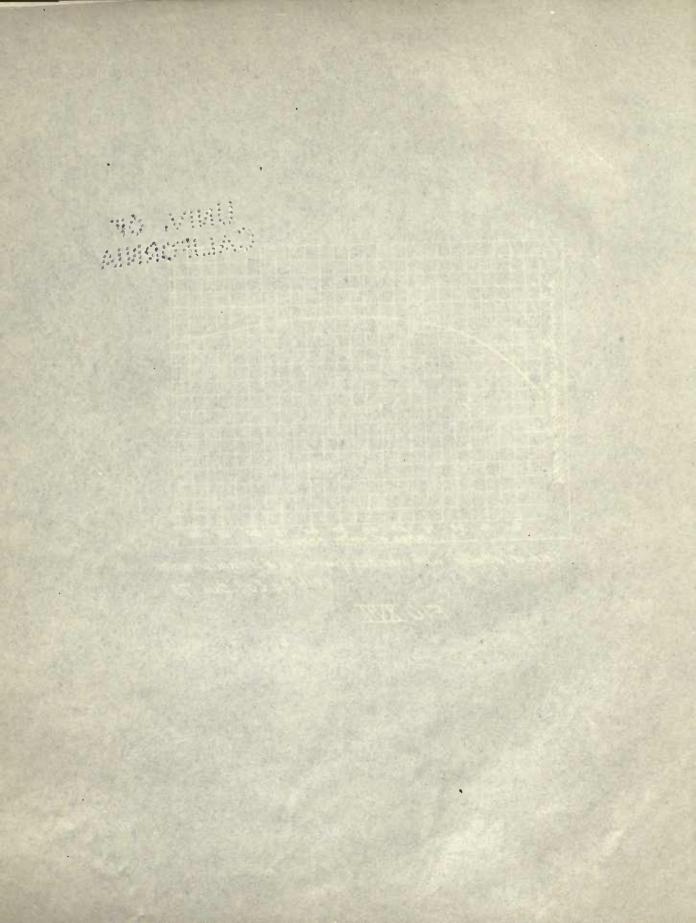
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Yield of alfalfa with various quantifies of irrigation water Utah Ag. Coll. Bul 173

FIG XVII



	10 10		lfalf		ucerne)		1
Acre inches water	'Numb		i	Num yea	ber of	Yield in per acre	tons
			13	times even if a	1	per aure	3
0		14	al- 1	a the	11	2,655	
5	!	36	- 1		-7	1 3,233	
10		28		8 +		3,923	
1. 1. 1. 1. 1. 1. 1. 1. 1. 1. 1. 1. 1. 1		6 6				J 1	
12.5		3	Si I	en		3,783	
15	18:00	30		8 5	14	4,294	
20	11 00	12		.61	172 1	4,165	
1	5 05	- 6 - 5		n in		31. 21	
22.5	100 1 00 68 1 00	1 .01		50 G	-1	4.090	
25	18,18	14	297	ກົ້ທີ		4.544	
30	59	10		3 8	.60	4.515	
32.5	5.55	2	The based	14,84 14,84	2	4.841	
35	0.0	3	1	n en	3	4.198	
37.5	100	1.88	5 1	n 6	81	4.400	
40	80, 00	Q4 0		62.1	4	3.740	
45	101 14	82 8	44 A	-41	2	4.613	
50	81 63	8	100	1 10 1 10	8	5.355	
52.5	1 5	2			2	3.718	
60		- 1	1			4.691	
65	10: 12	8,8	- 83 -	20 20 20 20 20 20 20 20 20 20 20 20 20 2	1	3.399	
	2 18	8 5	10	8 8		1	
67.5	1	1	1		l	4.230	
75	1	1	1		1	5.007	
90	1	l	1		l	4.520	
97.5	1	1	1		1	1 3.768	

The Utah results are tabulated in Table XXX and illustrated in Figure XVII.//3/

		LBLLA	Acre inches
Yield in tons	Number of	Number of	water
per sore	years .	etetri'	LOUAN.
2,655	1 11	<u>5</u> 1 1	0
5,285	4 1	1 36	5
5,923	; 11	1 28	10
2,783	۱ ۱	1 3	12.5
4,294	1	1 30	15
4,165	12	1 12	20
090.0 t	1 1	L I	22.5
4.544	1 12	1 14	25
4.515	1 10	1 10	30
4.841	1 * 2	1 2 1	52.5
4.198	1 3	1 3	55
4.400	1 1	T I	37.5
5.740	4	4	40
4.613	S I	۱ <u>.</u> ۶	45
5.355	8 1	8 1	50
5.718	S 4	۱ ۱	52.5
4.691	1 I.	I I	60
3.599	i t l	1 1	65
4.230	1 <u>1</u>	L i	67.5
5.007	I I	1	75
4.520	1 2	1	90
i 5.766	1	i I i	97.5

The Utah results are tabulated in Table XXX and illustrated in Figure XVII. (13)

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The results on alfalfa obtained at Davis are as follows:

4	4	4	4	41	¢3	N	0	No. of 1 nri- tions
1 15	1 12 1		1 7.5	6	6	6		Depth at each inri- tion tion
60	48	36	30	24	18	12	l	Depth ap- plied inches
1 10.17 7.25 10.70 5.55 8.42	18.45 9.52 8.63 8.85 10.62 8.05 9.02	17.58 9.33 9.38 8.22 12.48 8.63 9.27	17.53 9.54 9.43 7.97 11 06 8.32 8.98	6.00 8.38 8.32 6.89 9.96 7.96 7.92	1 1 17.02 5.69 8.02 6.46 6.80	<sup>1</sup> 4.78 <sup>1</sup> 7.52 <sup>1</sup> 6.51 <sup>1</sup> 4.31 <sup>1</sup> 5.83 <sup>1</sup> 4.84 <sup>1</sup> 5.63	13.85 5.94 5.52 2.75 2.89 2.35 3.88	Yield in Tons "1910,1911,1912,1913,1914,1915,Aver
.58.94	63.14	64,89	162.86	55.44	147.00	139.41	127.16	Aver- age value per acre at \$7 ton
29.44	29.10	27.96	26.45	23.22	19.35	15.37	8.73	Aver- age of pro- duction acre
1 29.50	34.04	36.93	36.41	32.22	28.25	24.04	1 18.43	Average profit acre

agrheultarel lands in the semi-bunic Willamstre Velley."

TABLE XXXI/VS/

The results on alfalfs obtained at Davis are as follows:

0.0	11111111111111111111111111111111111111		0	03	64	41	41	4	41	411
"Depth	asch Arri- 188- 188-	Indias		 0		6	N. 5	0	TS .	T RD
10	inches spinet		1	5	18	54	100	38.	34	80 .
		JATO	38.85	87.4'	 1	100.0¢	7.53	83.71	34.8	-
		, TOTT	15.94	\$6. V <sup>1</sup>	1	58.8	19. 54 1	82.0	833.8	1
		TOIS	20.00	LG. 91	\$0. Y	S	0.45	9.58	\$9.82	JO.TY
	1d An	17872	37.51	4·21	69.3	6.39	76.77	925.0 <sup>1</sup>	88.83	6S.V <sup>1</sup>
	Tons	, TOTA	68.3	28.31	\$0.8'	36.6	JT OC	12.48	TO. 62	JO.YO
		1 17872	03.50	4.84	97 · 9	96. P	\$5.8	8.63	30.8	dd.d'
		AVer-	88.8	80.0	08.8	14.98	86.8	72.01	\$0.8	8.42
AGL1	ASSO VSLUO VSLUO SCTO SCTO	CH CH	SA.IG	129.41	147.00	25. 44	68. So <sup>1</sup>	68.49	.02.14	. 98 . 94
AVer-	age coat of pro- duction	0	SV. 8	T5.57	19.35	22.82	36.4D	96.YS	58° TO	S9.44
AVETAGE	eros		10.45	24·04	dg.83	88.88	14.92	36.93	PQ.04	03.83

In the Modesto Turlock district investigations were conducted during the years 1916, 1917 and 1918. The results are shown in the following Table.

TABLE	XXXII	23/
-------	-------	-----

Check No.	19:	16^	1 1 1	917	1 1 191	18
1911 1911 1911 1912 1912	Amount of water applied inches	yield tons per	Amount of water applied inches	yield tons per	Amount of wa- ter ap- plied inches	Total yield tons per acre
1	30.04	7.68			41.86	6.64
2	36.05	8.74	68.44	6.73	55.01	1 5.06
3	22.06	8.01	29.42	6.92	45.44	6.17
4	17.21	7.91	21.59	6.94	18.45	6.41
5	25.25	8.91	29.75	1 6 <b>.9</b> 6	38.71	1 6.58
6	22.39	8.73	35.12	7.09	28.11	1 6.75
7	29.41	9.52	44.42	7.00	47.75	1 6.43
8	28.93	9.56	45.64	7.64	1 36.99	1 6.63
. 9	26.72	8.9	47.77	4.25	41.93	5.71

In Oregon--at Corvallis--similar experiments were conducted for the purpose "of determining the value of irrigation for increasing and insuring productiveness of the agricultural lands in the semi-humid Willamette Valley."

In the Modesto Turlock district investigations were conducted during the years 1916, 1917 and 1918. The results are shown in the following Table.

81	i 1 191	1917		1 1916		Check No.
Total yield tons per acre	of wa- ter ap- plied	yield tons per scre		yield tons per	of water	
\$6.84	41.86		an 198	88.7	30.04	l
5.06	55.01	6.73	68,44	8.74	36.05	2
6.17	45.44	6.92	29.42	8.01	80.28	3
6.41	18.45	6.94	21.59	7.91	17.21	1 <u>4</u>
6.58	38.71	6.96	29.75	8.91	25.25	5
6.75	26.11	80.4	35.12	8.73	22.39	0
6.43	47.75	7.00	44.42	9.52	29.41	1 7
6.63	56.99	7.64	45.64	9.56	28.93	1 8
5.71	41.93	4.25	47.77	. 0.8	26.72	6

TABLE XXXII/23/

In Oregon--at Corvallis -- similar experiments were

conducted for the purpose "of determining the value of irrigation for increasing and insuring productiveness of the agricultural lands in the semi-humid Willamette Valley."

. The following Table shows the results on Alfalfa

TABLE XXXIII ///
------------------

Participation (1997)	
Soll of water ap- 'In tong per 'plied in feet wore	Total yield in tons per acre
A. Value of harrowing and irrigating for	
new seeding 1911 (seeded 1909 without irrigation) 1911 (seeded 1909 with irrigation harrowed) 1911 (seeded 1909 with irrigation unharrowed) 1912 (seeded 1909 without irrigation) 1912 (seeded 1909 with irrigation harrowed) 1912 (seeded 1909 with irrigation unharrowed)	$\begin{array}{c} 2.17 \\ 4.16 \\ 4.08 \\ 4.00 \\ 5.42 \\ 4.10 \end{array}$
<ul> <li>B. <u>Irrigation before and after cutting</u></li> <li>1911 6" before cutting</li> <li>1911 6" after cutting</li> <li>1912 2 irrigations of 5" before cutting</li> <li>1912 2 irrigations of 5" after cutting</li> </ul>	4.41 4.59 10.37 10.30
C. Furrows versus flooding 1912 one 5" irrigation with furrows 1912 one 5" irrigation with furrows	6.37
D. <u>Amount of irrigation</u> 1911 2 irrigations of 4", total 8" 1911 3 irrigations of 4", total 12" 1912 2 irrigations of 4", total 8" 1912 2 irrigations of 6", total 12"	4.51
1913 (seeded 1909 without irrigation) 1913 l irrigation of 4", total 4" 1913 l irrigation of 6", total 6" 1913 2 irrigations of 4", total 8"	$\begin{array}{c} 2.15 \\ 3.80 \\ 4.22 \\ 4.22 \end{array}$

Alfalfa was weighed as green feed in 1912 and as cured hay in 1911 and 1913.

# . The following Table shows the results on Alfalfa

	the second	and a state of the
'Total	Year and Treatment	
bleiv		
'in tons		
'per		
lacre		
1		A
1	TOT GUIDENTIT THE STATE OF THE STATE	. A
1	16W SCECING	
1 2.17	1911 (seeded 1909 without irrigation)	
4.16	is a stor in the work of the solution of the store of the	
4.08	the second waster ter ter to two seconds 1 1 4	
4.00	LAALA LADDUGU LOUD WITTIN THAT AND AN ANT AN ANT AN ANT AN	
5.42	(Several antitepiret ditw 2081 030008/ 2161	
4.10	1912 (seeded 1909 with irrigation unharrowed)	
01.4		
	Irrigation before and after cutting	в.
PA A	LALL D" DETORE CUTATION	
4.41	LULL 6" after outtine	
4.59	1912 2 irrigations of 5" before autitat	
10.37	1912 2 irrigations of 5" after cutting	
10.50	MULTOPPO TOOTO O TO SHEET O	
	Furrows versus flooding	. 0
	1912 one 5" irrigation with furrows	
6.37	1912 one 5" irrigation with furrows	
5.17	ANOTINI ININ HOLONGLIN A	
	Amount of irrigation	D.
	"8 Isid 2 irrigations of 4", total 8"	
4.51	1911 3 irrigations of 4", total 12"	
5.22	1912 2 impleations of 4", total 8"	
6.70	1912 2 irrigations of 4", total 8" 1912 2 irrigations of 6", total 12"	
7.75	"SI IBJOJ ( 0.10 divisedina a such	
	1913 (caadad 1900 without trusters) 2191	1
2.15	1913 (seeded 1909 without irrigation)	
3.80	1913 1 irrigation of 4", total 4"	
4.22	CI LDUUU . U AV AND TO THE F	
4.22	1913 2 irrigations of 4", total 8"	

TABLE XXXIII/M/

Alfalfa was weighed as green feed in 1912 and as cured hay

in 1911 and 1913.

The experiments conducted at Idaho during 1910 -- 1914 give the following summarized results.

### TABLE XXXIV (Harding)

Class of	Average depth of water ap- plied in feet	
'Clay loam 'areas	2.40	1 1 4.91
Areas making	ofensor lowers	obnos to the
yield in each experiment	1 1 2.73	5.47

An examination of the results for alfalfa shows that this crop can profitably use much larger quantities of water than most other crops grown under irrigation. There is a decline in yield after a certain maximum amount of water is applied, but the decline is slow. Alfalfa is seen to be much less sensitive to over irrigation than potatoes and cereals. The Utah results show a maximum yield with fifty acre inches, although twenty-five inches gave very nearly the same amount i. e. a saving of fifty percent of water gave only a 15.2 percent decrease in crop yield.

In the case of the Davis experiments at the end of the six year experimental period, the stand on the areas given the heaviest irrigations was only 27 percent of the original stand, the excess use having enabled grass to come

1 H 50-

Li tret hits

The experiments conducted at Idaho during 1910

-- 1914 give the following summarized results.

in tons per	Average depth of water ap- plied in feet	. ifos
4.91	2.40	Clay loam
5.47	2.75	Areas making maximum yield in each experiment
		1

TABLE XXXIV (Harding)

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In 1918 the best yield at Modesto was with a total depth of 28.11 inches.

In Oregon Professor Powers comes to the following conclusion, "The maximum yield of alfalfa in all trials has been secured in the dry seasons with ten or twelve inches of water, but in wet seasons with six inches of water. The most economical increase in yield with irrigation has been secured with four to six inches of water."

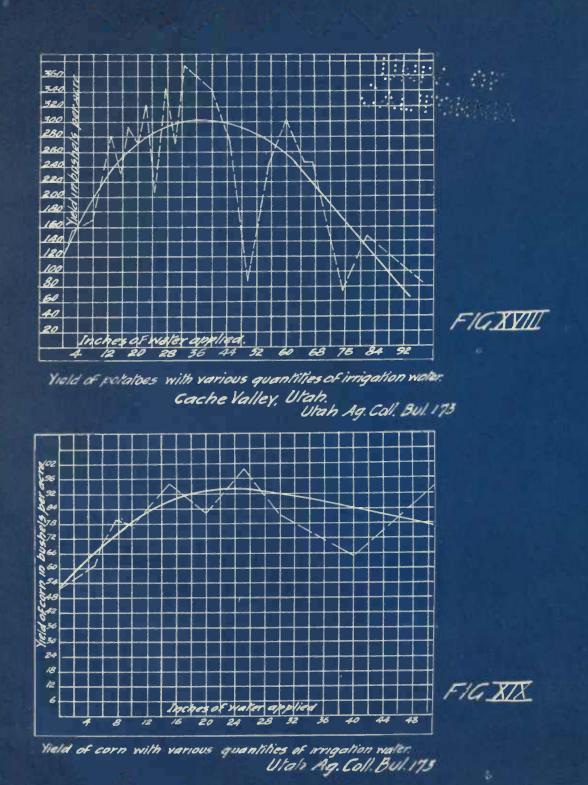
Potatoes. Table XXXV and Figure XVIII show the Utah results for this crop. Although considerable variation is noted in the trials during the different years (the experiments extended through fourteen years and the Table shows the average of two hundred sixteen trials), the general tendencies are distinct. The most favourable amount of water for potatoes seems to be between thirty and forty inches. For applications above sixty inches the yield drops very rapidly. This is probably due in part to the fact that excessive water prevents the tubers from securing the supply of air needed for optimum growth. into the alfalfa. The best stands at the end were areas given thirty to thirty-six inches of water, --which is undoubtedly the most desirable quantity for the irrigation of alfalfa under general Sacramento Valley and San Joaquin Valley conditions.

116

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· TOURSER ? 

Acre inches applied	No. of trials	No. of years	Yield in bushels per acre
None	12	12	117.37
2.5	Year and Tr	etment 4	157.19
5.0011a	39 son	1 14	162.23
7.5 Dry	20	9	135.165.38
10 <sup>3</sup> irrl	. 39	14	250 217.24
12.5	4	4	284.87
15 2	39	1 14	228.62
17.5	1 1	1 1	293.75
20 3	1 13	13	266.53
22.5	2	2	321.18
25 2	1 4	4	308 204.02
27.5	2	2	345.50
30 1915we	T Season 7	1 7	269.92 .
32.5 i immi	tation <sup>4</sup> of 2	4	377.59
40	1 2 3	. 2	213 341.44
45 2	1 8 1 2	8	145 271.39
50	! 1	1 1	83.45
55 The s	yerare reau	ta with po	240.00
60 for the	our years,	1910-61914	304.00
65	1 1	1 1	246.00
67.5	¦ 1	1 1	245.00
75	1 1	1	149.00
82.5 97.5	2	2	149.00 85.00

	172	12			
100	CV2	Ain	L 22	1204	the second

		10.04	Acre inches
Yield in bushels per sere	No. of Vears	to .04	applied
117.57	12	1 12	None
157.19	1 1		2.5
1 162.23	1 1	1 1 39	5.0
165.58	' 0 i	20	7.5
217.24	1 14	88	10
284.87	1 4	<u>▶</u> 1	12.5
28.62	1 14	89	15
293.75	Ξ I	1	17.5
266.53	15	' 15	20
521.18	S 1	2 I 1	22.5
204.02	4	. 4 .	25
545.50	2	S 4	27.5
269.92 •	7	1 7	80
377.59	4	4 4	52.5
<b>341.4</b> 4	8	S f	40
271.39	8	8 F	45
85.45		1 1	50
240,00	5	r 3	55
304.00	r ð !	8	60
246.00	L I	1	65
245.00	i i i	1	67.5
149.00	1 for the second	1	75
149.00 85.00	9 A	E E	82.5 97.5

and the second second second

### The Oregon results are as follows: TABLE XXXVI////

tions		d Treatment	'Yield in 'bushels 'per acre
<u>1911</u> Dry	a dry sea	son 169	135.1
3 ir	rigations	of l"72	250.9
- 1	6 и	" 3"85	176.4
2	11	" 2코"	240.7
			190.9 vet
			254.9
ith 2	inches of	wutgu. The	258.1 00100
			308.5
			292.5
<u>1913</u> Dry	vet seaso	n vield of	38.6 bushels pe 109.8
lin	igation	of 2"	172.2
not <sup>1</sup> be a	H dvisable	" 3" profitab	213.3
2		." 2"	' 145.2

The average results with potatoes at Gooding, Idaho, for the four years, 1910--1914 are in Table XXXVII.

# The Oregon results are as follows:

'Yield in	Year and Treatment	
bushels	•	
per acre		FFOF
135.i	a dry season	ud TTGT
250.9	irrigations of 1"	5 5
176.4	а 2 п п	Ţ
240.7	" 2 <u>3</u> "	S
1 190.9	"S "	1
254.9	"S " "	3
258.1	n 2 n	2
308.5	и С. и и	2
292.5	n 2 n − n .	3
1	-wet season	1915-
109.8		Dry
1 172.2	rrigation of 2"	1 1
215.8	" S "	1
145.2	<sup>11</sup> S <sup>11</sup> 11	8

The average results with potatoes at Gooding, Idaho, for the four years, 1910--1914 are in Table XXXVII.

TABLE XXXVII (Harding)

Total water applied in feet	
.69	1 3.2 1
1 1.72	6.75
2.83	1 6.7 1 1 1
	applied in feet .69 1 1.72

In Oregon the maximum yield for the wet season was with three inches of water, while in the dry season it was with six inches of water. The most economical yield of potatoes obtained in the course of the experiments was secured with the aid of three one inch irrigations, applied ten days apart, giving a yield of 38.6 bushels per acre inch.

In Idaho, the conclusion was reached that it would not be advisable or profitable to apply more than two to two and one-half acre feet per acre on clay loam soils.

<u>Cereals</u>. Experiments at Utah on corn were conducted through a period of seventeen years with the following results, given in Table XXXVIII and Figure XIX.

## TABLE XXXVII (Handing)

Mield tons per scre	Total water applied in feet	No. of irriga- tions
5.2	69.	2
6.75	1.72	4
6.7	2.85	. 3

In Oregon the maximum yield for the wet season was with three inches of water, while in the dry season it was with six inches of water. The most economical yield of potatoes obtained in the course of the experiments was secured with the aid of three one inch irrigations, applied ten days apart, giving a yield of 38.6 bushels per acre inch.

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TABLE XXXVIII/13/

Acre inches applied	'No. of 'trials	No. of years	Yield in bu- shels per acre
' None	13	1 13	57.33
' 5 1	1 13	1 13	61.39
17.5	8	1 8	79.14
110	1 17	1 17	1 77.23
15	8	! 8 r	1 93.93 I
120	17	1 17	' 81.80 '
125	8	t 8	99.16
130 t	17	1 17	81.49
<sup>1</sup> 40	. 9	1 9	65.30
155	8	1 8	96.78

On the San Joaquin and King's River Canal system the following results were obtained.

### TABLE XXXIX

Year		of water ap- 1
	plied	l in feet /
1907	1	2.13 1
1908		1.65
1911	1	1.38 "
	Average	1.72

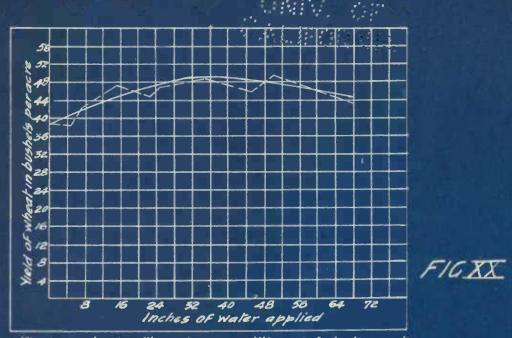
Sector Sector					
1.2.11		1 13	A A A		
1500	1. 1.	1. V	and had be	1.04	100
	Course in the	1000			

Yield in bu- bhels per sere	years	No. of trials	'Acre 'inches 'applied
57.33	13	13	None
61.39	1 13	13	, 5 <u>,</u>
79.14	8	8	7.5
77.25	17	T7	110 1
93.93	8	8	115 * 1
81.80	IV I	17	081
99.16	8	8	25
81.49	17	17	081
65.30	6	6	40
1 87.88	8	1 8	55

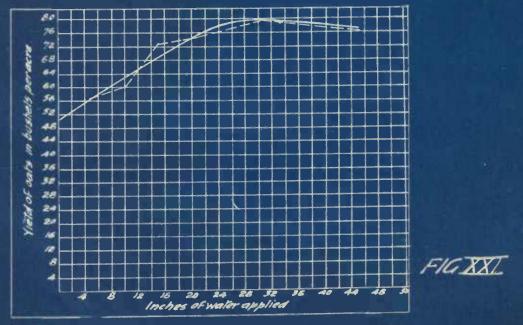
On the San Joaquin and King's River Canal system the following results were obtained.

#### LABLE XXXIX

ap- i	th of water ed in feet	Dep pli	TSOL
t I	2.13	1	1 1907
1	1.65		1 1908 i 1908
1	1.38		1911
	1.72	aganevA	



Yield of wheat with various quantities of irrigation water. Utah Ag. Coll. Bul. 173



Vield of oats with various quantities of irrigation water. Urah Aq. Coll. Bul. 173

- 10 Con 1946 - 1967

The Utah results on wheat, extending through a lowperiod of thirteen years are given in Table XL and Figure XX. TABLE XLI (Hording)

TABLE	XL(13)	
-------	--------	--

NO.	or ir- T	otal wat	er Yield of
Acre inches applied	'No. of 'trials	'No. of 'years	Yield per acre
		1 0.	Grain 'Straw 'bushels'pounds
None	1 9	1 9	38.37 3982
5	1 34	13	38.23 3540
7.5	1 18	1 9	41.54 3301
10	38	1 13	42.90 4142
15	1 34	1 13	47.10 4796
20	1 4	1 4	45.70 5940
22.5	1 4 Wheat ex	1 4	44.60 6757
25	18	9 bilowing	46.46 4311
35	¦ 18	1 9	48.55 4755
45	4	1 4	45.80 6250
50	1 18	1 9	49.38 5332
67.5	1 4	1 4 1	' 43.50 ' 5794

The Utah results on wheat, extending through a period of thirteen years are given in Table XL and Figure XX.

				and the second second second second second
der acre	1	lo .ol stears	lo .ol trials	Acre inches applied
'Strew counds	Grain bushel		1	
	78.87	6 1	6	None
5540	1 38.23	15	54	5
3501 \	1 41.54	6	18	7.5
4142	42.90	13	38	10
- 4796	· 47.10	13	34	15
5940	45.70	4	4	20
6757	44.60	4	· 4	22.5
4513	46.46	6	18 1	25
4755	48.55	. 0	18 . 1	35
6250	45.80	4	1 1	45
5832	49.38	6	18	50
5794	45.50	\$	4	67.5

TABLE XL/15/

The experiments at Gooding, Idaho, gave the follow-

TABLE XLI (Harding)

		-	and the second se	Suburger or a the for the second
	No. of rigatio	ir- ons	Total water absorbed per acre foot per acre	'Yield of ' 'grain ' 'bushels ' 'per acre'
	0	in	0	13.3
	1 1		.36	23.3
P	3	ac the	.75	28.7
th	4		1.23	31.8
1	6	1	1.76	33.1
1	8	1	2.27	36.0
1	9	1	2.94	27.5
	And the state of the state of the state of the state			

Results on wheat experiments at Davis, California, during 1912-1914 gave the following: The experiments at Gooding, Idaho, gave the Follow-

ing results.

		and the second sec
arain '	"Total water "absorbed per "acre foot "per acre	No. of ir- rigations
1 8.8	0	0
23.5	.36	t t
28.7	. 75	. 3 .
31.8 !	1.25	· · · · · · · · · · · · · · · · · · ·
35.1	1.76	ð 1
36.0	2.27	8 1
27.5	2.94	1 9 1

TABLE XLI (Harding)

Results on wheat experiments at Davis, California,

during 1912-1914 gave the following:

TABLE XLII

Acre	No. of ir- rigations	Depth ap-	Yield in pounds		
applied		inches	Hay	Grain	
	0		2703	637	
None	1 1	6.0	4267	1157	
5	1 2	1 10.1	6100	1529	
	2	1 15.5	1 5050	1029	

Typical practice is represented by Table XLIII which shows the net duty on grain in the San Joaquin Valley

TABLE XLIII

Year I	epth applied ft.
1907	.74
1908	.84
1911	•96
' 1913 '	ield as any treat 1.11
Average	.91 ft

period of six years -- Table XLIV and Figure XXI.

inches of mater would pay for the extra yield obtained.

and sold			100			
1	died	12		1	0.2	1

1.		Yield i	Depth ap-	No. of ir-
1	Grain	Hay	inches	
1	637	2705		0
1	1157	4267	0.0	1
1	1 1529	6100	10.1	8
1	1 1029	5050	1 15.5	Ś

Typical practice is represented by Table XAIII which shows the net duty on grain in the San Josquin Valley

TABLE XLIII

pth applied ft.	Tear De
47.	1907
. 84	1 1908
.98	1 1911
1.11	1 1913
49 10	ADBTAVA

Average .91 ft

At Utah. oats gave the following results for a period of six years -- Table XLIV and Figure XXI.

increasé i	n the yield	with an	increase in	weter up to			
Acre inches	No. of trials	No. of years		'Yield per acre			
ennlied	n were not gr n fifteen an			Straw in pounds	I. W		
None	The results	on corn	50.37	1876	ith		
tvent5-rr	ancies of						
	11 gulletitie			2107			
inches.	18	las fere	72,82	2563			
20 10	irrigatio	n apfilie	74.40	2723			
30 30 t	ne lease 3as wi	th patet	79.90	2774			
45	Citrus <sup>6</sup> Fruit	a. <sup>6</sup> n t	76.68	3149			

(California) for 1912-1914, the following data of the net

On the whole it will be seen that the yield of cereals is not nearly so much affected by irrigation as is the case with potatoes and alfalfa. In the case of the Utah experiments on wheat, for instance, fifteen inches of water gave almost as high a yield as any treatment and yet the yield kept up fairly well with the very heavy irrigations. It will be noted that where no irrigation water was applied the yield of wheat were fairly satisfactory. Therefore, in practice, it is doubtful whether more than fifteen inches of water would pay for the extra yield obtained.

Oats is a plant which is more sensitive to moisture than wheat. In the Utah results, there is a gradual

				in specific data
Straw in		No. of years	No. of trials	Acre inches applied
pounds	bushels		4	
1876	50.37	· 8	3	None
2077	57.51	9	21 <sup>1</sup>	×5
2107	60,18	9	18	1.0
2565	72.82	9	18	15
2723	74.40	9	6	000
2774	79.90	3	3	30
3149	76.68	9	1 0	45

TABLE XLIV /3/

On the whole it will be seen that the yield of cereals is not nearly so much affected by irrigation as is the case with potatoes and airaifa. In the case of the Utah experiments on wheat, for instance fifteen inches of water gave almost as high a yield as any treatment and yet the yield kept up fairly well with the very heavy irrigations. It will be noted that where no irrigation water was applied the yield of wheat were fairly satisfactory. Therefore, in practice, it is doubtful whether more than fifteen inches of water would pay for the extra yield obtained.

Oats is a plant which is more sensitive to moisture than whest. In the Utah results, there is a gradual increase in the yield with an increase in water up to thirty inches, above which the yield decreases slightly. The yields were not greatly different for quantities of water between fifteen and forty-five acre inches.

The results on corn show the highest yield with twenty-five inches of water, although yields are almost the same for all quantities of water between fifteen and thirty inches. While the yields were somewhat reduced by excessively large irrigation applications, this was not nearly so much the case as with potatoes.

<u>Citrus Fruits</u>. In the State Engineers Report (California) for 1912--1914, the following data of the net duty on citrus fruits in Southern California are given.

Del monte irrigation Company19082,000.73Del monte irrigation Company19092,000.73Pelomares irrigation Company1906600.71Falomares irrigation Company1907600.83Palomares irrigation Company1908600.83Falomares Irrigation Company1908600.83Falomares Irrigation Company1908600.83Falomares Irrigation Company1909600.83

increase in the yield with an increase in water up to thirty inches, above which the yield decreases slightly. The yields were not greatly different for quantities of water between fifteen and forty-five acre inches.

The results on corm show the highest yield with twenty-five inches of water, although yields are almost the same for all quantities of water between fifteen and thirty inches. While the yields were somewhat reduced by excessively large irrigation applications, this was not nearly so much the case as with potatoes.

<u>Citrus Fruits</u>. In the State Engineers Report (California) for 1912--1914, the following data of the net duty on citrus fruits in Southern California are given.

TABLE XLV

Location and Source of Supp.	ly 'Year i i i	Acreage	Depth of wa- ter applied feet
Gage Canal and Riverside Water Companies	' ' 1899-1905	1 180,667	2.25
Riverside Water Company	1901-1908	9,000	2.29
Riverside Water Company	1912	31.5	4.10
Riverside Water Company	1912	19	2.58
Santa Ana Valley Canal	1912	20	1.79
Santa Ana Valley Canal	1912	1 18.4	1.52
Del Monte Irrigation Company	y 1906	2,000	.73
Del Monte Irrigation Company	y 1907	2,000	1.10
Del Monte Irrigation Company	y ¦1908	2,000	.73
Del Monte Irrigation Company	y 1909	2,000	.73
Palomares Irrigation Compar	ny <b>1</b> 906	600	.71
Palomares Irrigation Company	y 1907	1 600	.83
Palomares Irrigation Company	1908	¦ 600	.83
Palomares Irrigation Company	1909	600	.83

S.LB.

# TABLE XLV

Location and Source of Supply	Tear L	Acreage	Depth of wa-
and the second	1 1 1		ter applied feet
Gage Canal and Riverside Water Companies	1899-1903	1	2.25
Riverside Water Company	1901-1908	000.0	2.29
Riverside Water Company	1912	31.5	4.10
Riverside Water Company	, 1915	1 6T	2.58
Santa Ana Valley Canal	1912	20	1.79
Santa Ana Valley Canal	, 1915	18.4	1.52
Del Monte Irrigation Company	1906	2,000	.73
Del Monte Irrigation Company	1907	2,000	1.10
Del Monte Irrigation Company	1908	2,000	.73
Del Monte Irrigation Company.	1909	1 000.S	57.
Palomares Irrigation Company	1906	1 000	.71
Palomares Irrigation Company	1907	600	. 83.
alomares Irrigation Company	1908	000	.85
alomeres Irrigation Company	1909	600	58.

# Deciduous Orchards and Vineyards

TABLE XLVI

Location and source of supply	'Year	Acreage	Depth applied feet	Remarks
<u>Sierra Foothills</u> South Yuba Water Co. Bear River Canal		'6,900 '5,000	1 1 2.62 1 2.62	
Sacramento Valley Palermo Land & Water Co.	' 1912	33	.75	Prunes
Palermo Land & Water Co.	1912	10.5	1.64	Olives
Palermo Land & Water Co.	1912	1 10	.80	Olives and Peaches
Yolo Water & Power Co	. 1913	1 14.2	2.29	Prunes
Orland Project	<b>'1914</b>	1 14.2	.25	Young Almonds
<u>San Joaquin Valley</u> Turlock Canal Pumping plants at	' '1909 '	1 1 37.8	.38	One irrigation
Madera Fresno Canal San Joaquin & Kings	'1910 '1910 '1906	160	.86 .49	No irrigation One irrigation
River Canal San Joaquin & Kings	'07 '1907		2.64	
River Canal Pumping plants at	108	15	2.38	1
Friant Pumping plants at	'1912 '	20	.83	'Two irrigations
Friant	'1912 '	150	· .06	1
Southern California Santa Ana Valley	t t	1	1	t t
Canal Santa Ana Valley	¦1912	1 15	4.83	Walnuts
Canal	¦1912	' 21 '	' 3.18	Walnuts

# Deciduous Orchards and Vineyards

TABLE XLVI

Remarks	Depth	Acreage	Year	Location and source of
1	applied			subply
1	feet		1.5	1
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		1		Sterra Foothills
1	2.62	000 01	0001	South Yuba Water Co.
	2.62	5.000		
	20.2	000.0	GOGT	Dear wiver caust
		1.		La bistore : An Le belle - Contra L
and the second se				Sacramento Valley
		- North Contraction of the Contr	12000	Palermo Land &
Frunes	.75	33	1912	
				Palermo Land &
'Olives	1.64	10.5	1912	.o0 rejeW
		1	1	Palermo Land &
Olives and	08.	1 10	1912	. Water Co.
Peaches		1	1	
and the second second second second		1		Further (Safety and Annual -
Prunes	2.29	1 14.2	1918	Yolo Water & Power Co.
		1	1	100, 10000 m 100000 0101
Young Almonds	.25	1 14.2	1914	Orland Project
Contourte Stroot	ou.	un establista	ETAT!	anafair mierin
		1	1	TAFFAT STATES
One irrigation	88.	8.75	1909	San Joaquin Valley
norregiurit and	00.	0.10	COST	
		000 1	1 - S 1	Pumping plants at
noiteginni ol	38.		1910	and the second
One irrigation	.49		1910	
			1906	
	2.64		70!	
	1		1907	
	2.38	1 15	80	River Canal
1	1	1	1	Fumping plants at
'Two tirrigations	86. '	20	1912	Friant
1	1	1	1	Fumping plants at
1	80. 1	1 150	1918	
1	1	1	1	
1	1	1	1	Southern California
1	1	1	1	Santa Ana Valley
Walnuts	4.83	1 15	1912	Canta Ana valtey
CONSTRUE	00.2	OL I	2721	
*Walnuts	or a l	FO 1	orari	Santa Ana Valley
SO DUT 100	01.0	1 21	1912	- Canal
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Carlsbad	Truckee Carson	North Platte	Minnidoka South	Minnidoka North	Boise Project	Orland Project	Yuma River	Salt River	Project scheme	Showing the
95,196	1263,432	Platte'388,963	1238,886	, 365,331	1585,205	1 74,032	337,597	1994,733	Amount divert-	gross and
1,144	53,036	4,282	22,241	7,843	16,858	9,373	337,597 115,715	994,733 22,067 435,155 537,511 201,601 54	Amount wasted acre	net
54,463	85,021	,282 160,849 1777,472	87,403 129,242	7,843 178,474 179,014	16,858 <sup>1</sup> 209,864 <sup>1</sup> 358,483 <sup>1</sup> 116,686	9,373 20,210	85,351 <sup>1</sup> 136,531	435,155	Amount Lost acre feet	duty for v
39,589 1	85,021 125,375	177,472	129,242	179,014	358,483	44,449	136,531	537,511	Amount applied acre feet	for various irrigation project for the year 1917.
16,882,41.6	40,392 <mark>1</mark> 47.6	83,203 45.5	43,220 54.0	50,479 <mark>1</mark> 49.1		12,729 <sup>1</sup> 60.1	36,956,40.6	201,601	Acerage	rious irrigation p for the year 1917.
41.6			54.0	49.1	61.3	60.1		54	'Per- 'cent 'ap- 'plied	n proj 17.
1.2	120.1	12.3	9.3	2.0	N.9	12.6	134.2	2. 2. 3	'rent 'vent 'wast-	Ø
157.2	132.3	41.2	136.7	148.9	135.8	127.3	125.2 10.55	43.7	'Per-'Gross 'cent'duty 'lost'	in the
5.53	6.53	4.68	5.54	7.24	5.02	5.82		4.93	1	U. 
12.33	13.11	12.13	12.99	ື ຜ 55	02 13.07	13.49	13.70	12.67	'Wet duty	Α.

CHAPTER X

# TABLE XLVII

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gi Asse-	1994 . V.55	703, 783 <sup>1</sup>	380.4Y	302.388 <sup>1</sup>	1202,351	1888,8881	386,883 <sup>1</sup> 9	\$354, 835 <sup>1</sup>	1 95,196
beret beret	780.SS	TTP'ATP	878.0	T9.858	3.5.6. T	SS 841	4 .282	580,83	I PPL . I
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lduty.	70.S <sup>1</sup>	07.3		70.8	10 10 10	68.3	ST.S	P.TT	88.S <sup>1</sup>

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65,042 76,265 83,714 97,127 101,316 116,686 116,686 110,000	27,887 31,428 33,428 41,463 41,463 53,275 58,275 58,270 58,270	Total area irri- gated
1244,000 1328,174 1410,912 1448,029 1607,180 1585,205 1824,462 1759,089	140,601 168,573 185,227 264,060 329,554 368,148 420,176	"Total "quanti- "ty wa- "ter di- "for di- "for di- "rect use "feet
122,644 1280,217 1219,695 1272,659 1360,907 1358,483	1133,912 1160,056 1171,268 1231,271 1299,432 1316,365 1367,144 1390,770	Total quanti- ty de- livered farms acre feet
3.77 4 4 5 5 6 7 5 7 5 7 5 7 5 7 5 7 5 7 5 7 5 7	40000000 4000000 400000000000000000000	Acre Per acre deliv- ered to farms
1.51 1.34 1.22 1.22 1.22 1.22 1.22 1.22 1.22	1.091 1.091 1.09 1.09 2.92	Total annual fall feet
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1,256 4,267 3,276 13,041 13,138 70,905 72,775	49,056 36,595 35,487 45,0487 47,9887 92,638	Total quanti- ty wa- ter di- verted for di- rect use acre feet
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5,068 7,660 5,743 12,656 6,020 15,744 21,075 21,075	6,824 7,419 6,613 4,243 6,6717 6,675 7,569 11,496	Total area irri- gated
15,432 30,088 25,769 40,141 27,181 60,205 51,445 70,029	20,392 24,628 24,763 15,538 17,841 25,481 30,087 42,863	Total quanti- ty wa- ter di- verted for di- rect use acre feet
6,058 10,250 9,143 17,970 7,545 27,842 26,252	11,688 11,187 11,468 4,654 5,757 9,091 11,193 24,000	Total quanti- ty de- livered to farms acre feet
1.19 1.34 1.34 1.42 1.42 1.25 1.25 1.25	1.30 1.32 1.32 1.32 1.32 1.32 1.30	Acre feet per acre deliv- tered farms
1.57 .90 1.16 1.48 1.48 1.60 1.73 .73 1.13 .80	1.42 1.42 .60	Total annual rain- fall feet
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25,050 243,913 30,857 186,175 28,651 268,028 40,295 235,691 39,400 264,185 40,392 263,432 42,311 266,927 42,311 266,927	Total Total area irri- gated ty wa- ty wa- ter di- rect use acre acre 56,829 56,829 56,829 70,000 70,000 297,045 85,203 297,908 
62,707 69,798 94,730 118,233 120,792 125,375 126,545 124,015	Total quanti- ty de- to de- livered farms acre feet 113,251 141,489 176,915 164,240 177,472 204,819
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03,71	13,63	46,07	488,286	56,18	16,92	44,61		00		98,92	61	5,47	9,53	7,90	6,56	5,08	-	Total quanti- ty wa- ter di- verted for di- rect use acre feet
74,94	48,29	52,39	0,64	99,95	61,55	20,60	(Not	neou	48,933	7,38	9,58	0,38	8,85	0,90	3,04	8,76		Trotal quanti- ty de- livered to farms acre feet
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23,834 18,928 24,440 27,254 29,351 33,365 35,268 37,881	4,600 5,100 5,300 7,327 9,100 9,100	Total area irri- gated
42,087 38,005 53,428 69,970 66,010 65,368 104,926 119,850	54,256 59,552 62,728 55,333 56,708 86,977 118,154 162,850	Total quanti- ty wa- ter di- verted for di- rect use acre feet
26.929 22,161 30,672 30,642 29,970 52,9970 52,090 52,090 52,090	37,950 422,250 36,300 29,552 31,557 45,367 48,163 53,500	Total quanti- ty de- livered farms acre feet
1.13 1.12 1.26 1.28 1.28 1.28 1.28	5.45 5.45 5.61	Acre feet per acre deliv- ered to farms
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25,947 25,947 25,182 9,770 12,844			ter di- verted for di- rect use	otal uant
20,035 18,580 19,615 19,900 6,339 9,967	2,40	30,390 47,349 54,262 1 <b>6</b> ,484 39,132	livered to farms acre feet	y and
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100,681 101,796 105,902 108,224 108,224 108,224 105,702 1105,702 1123,503	116,524 19,423 22,226 22,753 29,977 32,764 32,764 32,764	Total area inri- gated
	49,307 68,894 91,708 95,957 125,662 110,916 1162,463 199,061	Total quanti- ty wa- ter di- verted for di- rect use
1318,122 1337,349 1358,579 1356,435 1350,582 1364,578 1366,694	27,370 40,436 52,789 54,668 70,247 68,738 84,378 84,378	"Total . quant1 - ty de- "livered" to farms acre feet
2.22 2.22 2.22 2.22 2.22 2.22 2.22 2.2	80 80 80 80 80 80 80 80 80 80 80 80 80 8	Acre per acre deliv- to farms
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115,008 118,750 120,600 122,000 125,400 125,400 126,400	162,800 164,400 166,525 166,525 168,840 173,000 180,500 180,500	"Total "area "irri- "gated
47,675 59,509 67,788 62,000 75,911 80,377 90,280 98,223	1307,585 1320,512 1320,512 1329,903 1272,401 1349,262 1385,179 1415,097 1421,364	"Total "quanti- "ty wa- "ter di- "verted "for di- "rect use
34,445 42,539 40,376 49,412 57,318 64,068 70,776	1192,983 1204,940 1204,504 1268,852 1259,898 1254,280 1290,502 1295,215	Total quanti- ty de- livered to farms acre feet
00000000000000000000000000000000000000	3.25 27 37 37 37 37 37 37 37 37 37 37 37 37 37	Acre feet per acre deliv- to farms
L.086 .5755 .5757		Total annual rain- fall feet
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Average Seasonal Duty of Water on various Reclamation Service Projects 1912-1917 (inclusive)

Average	Salt River Yuma Orland Uncompahgre Boise Minnidoka North Minnidoka South Huntley Milk River Sun River Lower Yellowstone Yellowstone TruckeeCarson Carlsbad Rio Grande Umatilla Klamath Belle Fourche O'Kanogan Sunnyside Tieton Yakima	Scheme
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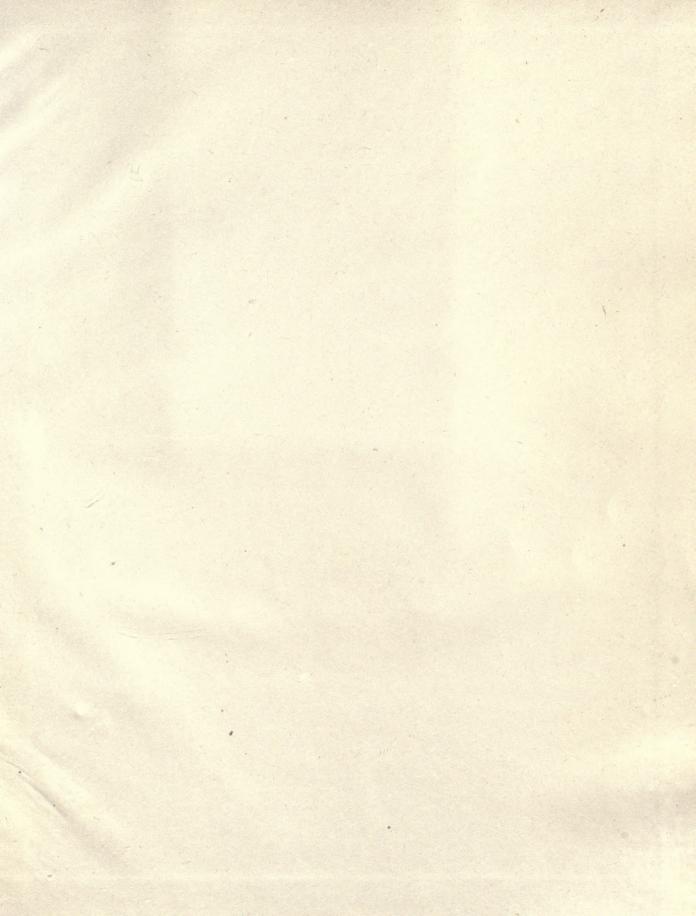
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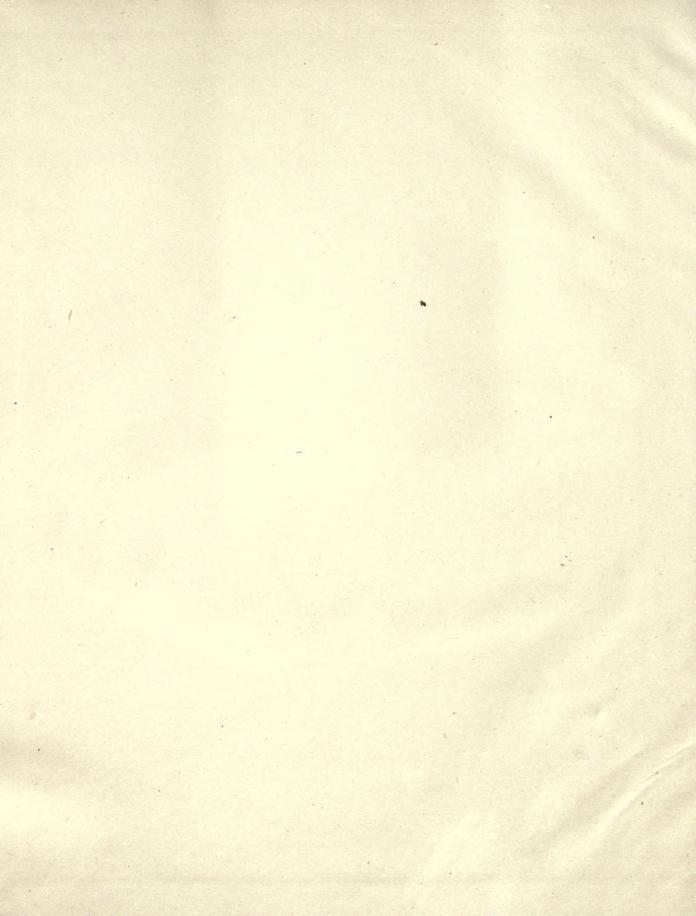
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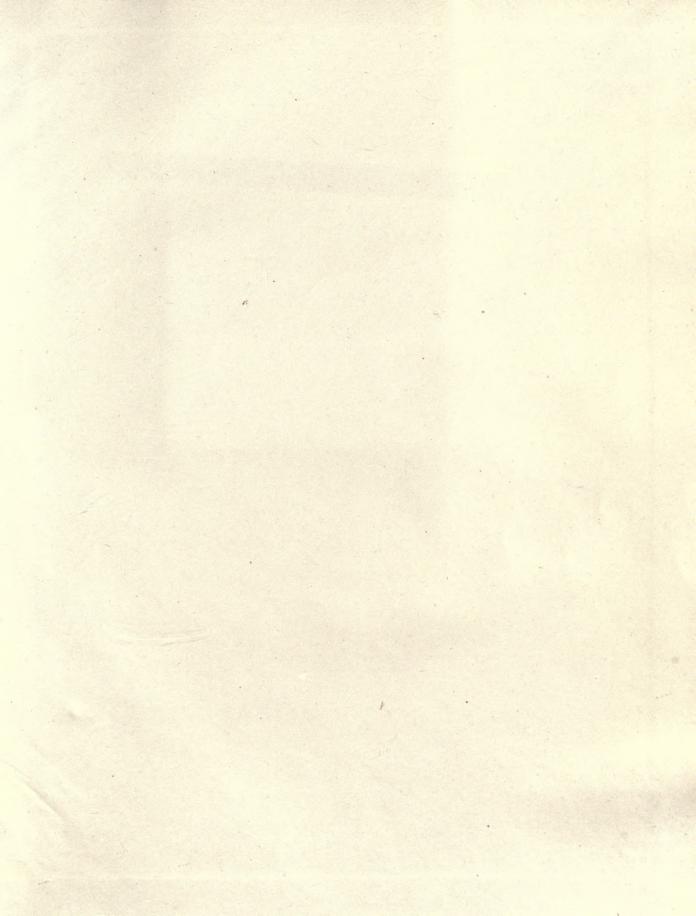
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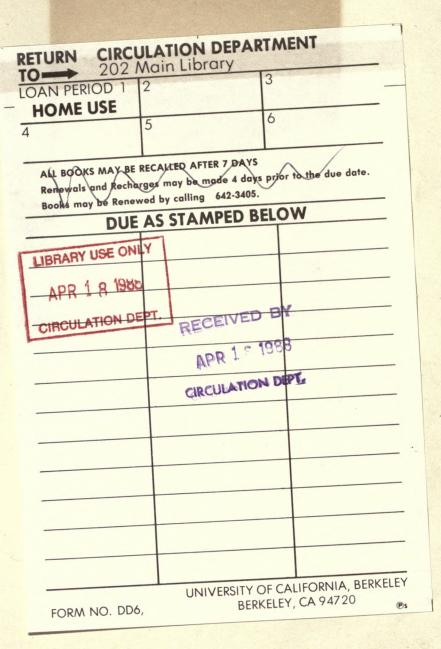
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